The Higgs Boson for the Masses?

Chris Quigg

Symmetry

Symmetry

Indistinguishable

before and after a transformation

Symmetry

Indistinguishable
before and after a transformation

Unobservable
quantity would vanish if symmetry held

Symmetry

Indistinguishable
before and after a transformation

Unobservable
quantity would vanish if symmetry held

Disorder
order = reduced symmetry

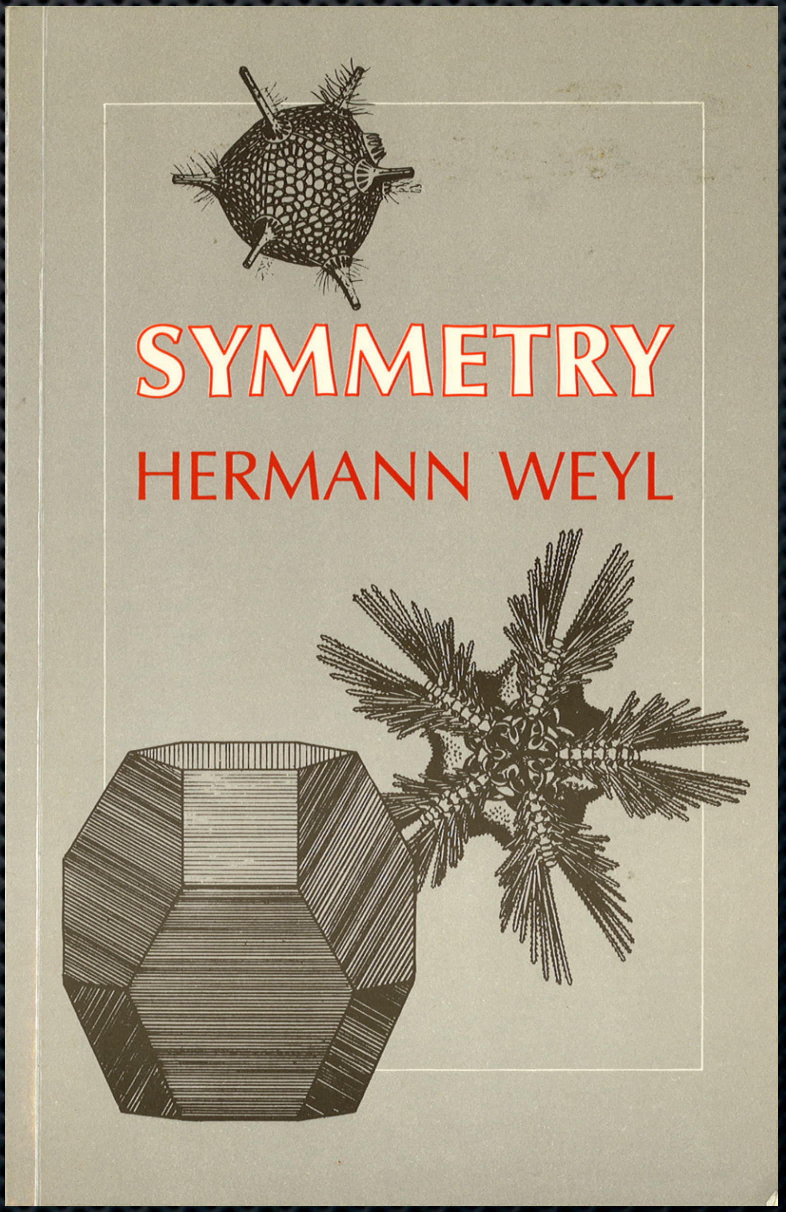
Symmetry

Bilateral

Translational, rotational, …

Ornamental

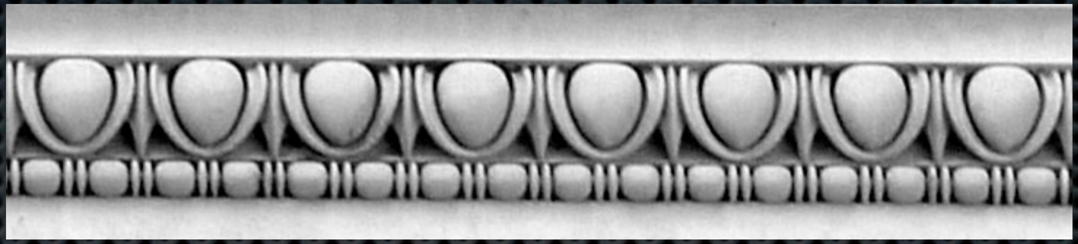
Crystals



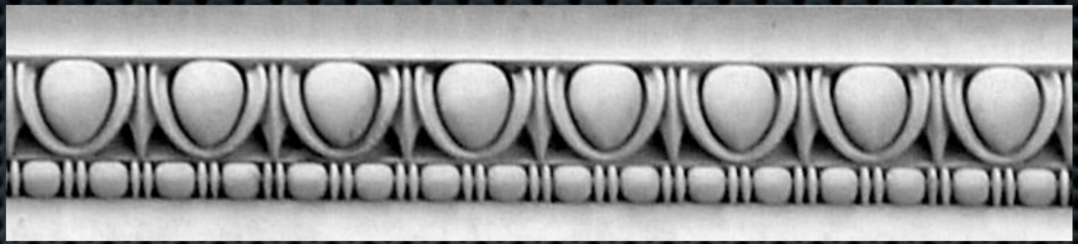
Symmetry

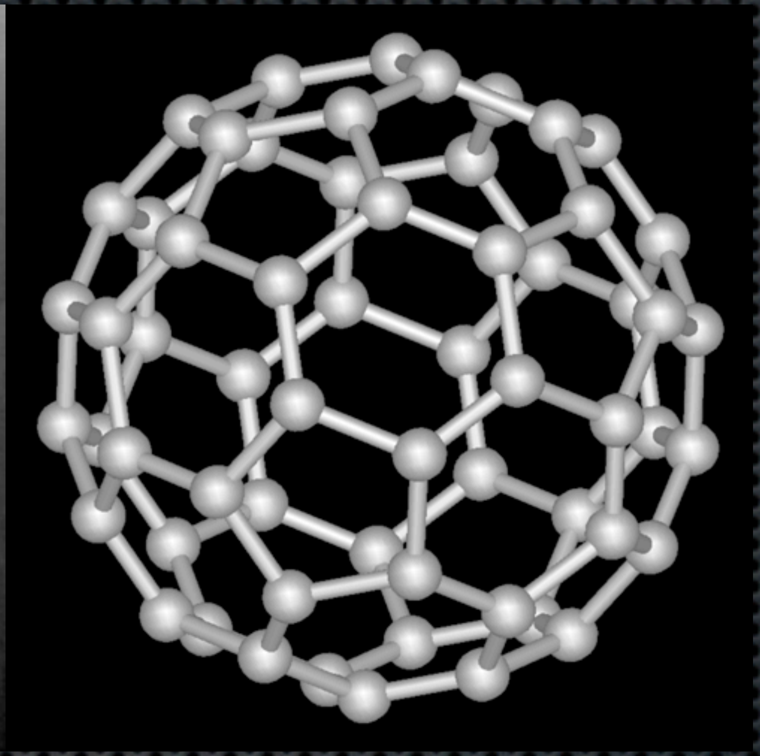
Symmetry

Symmetry



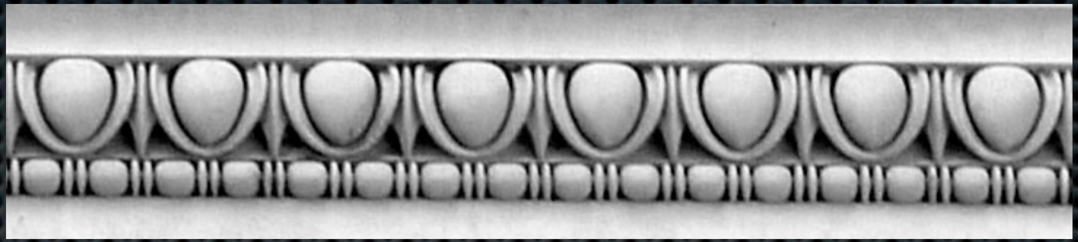
Symmetry

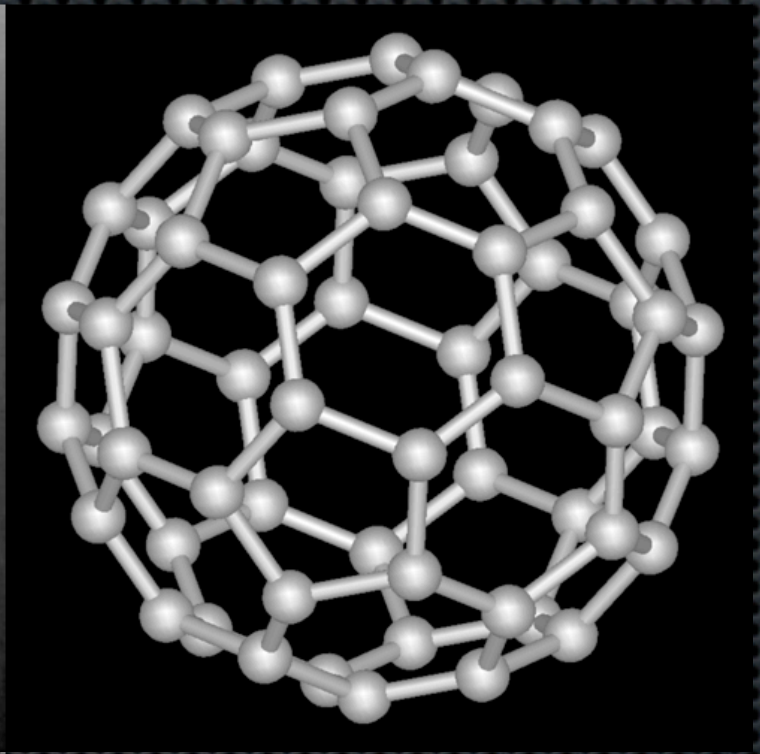




Fullerene C60 ball and stick created from a PDB using Piotr Rotkiewicz's [http://www.pirx.com/iMol/ iMol]. {{gfdl}} Source: English Wikipedia,

Symmetry





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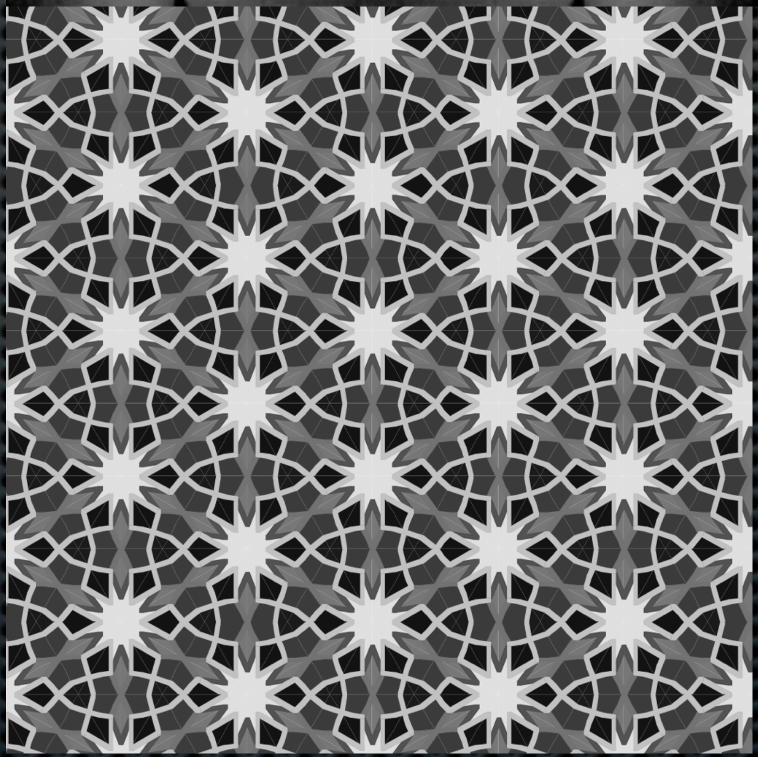
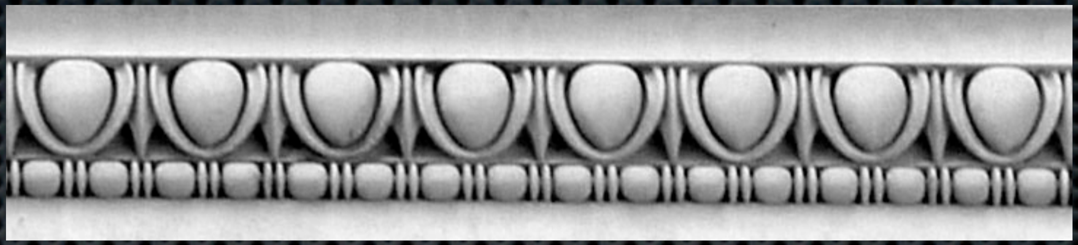
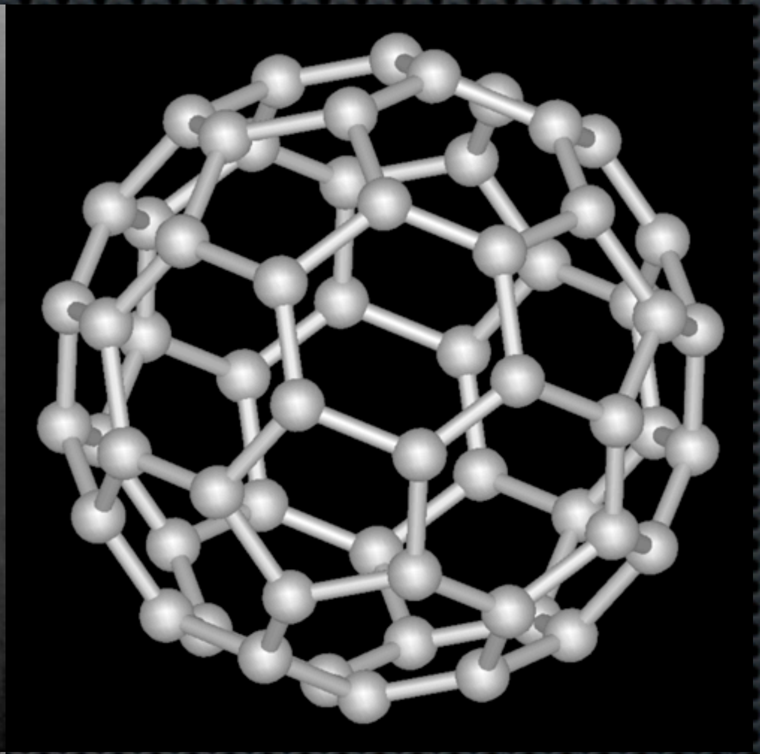


Symmetry





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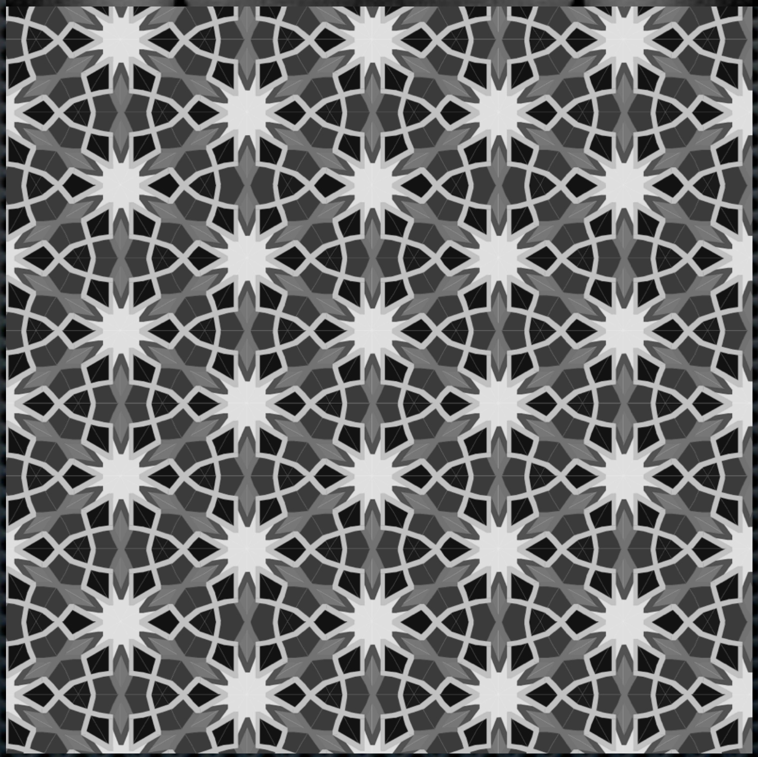

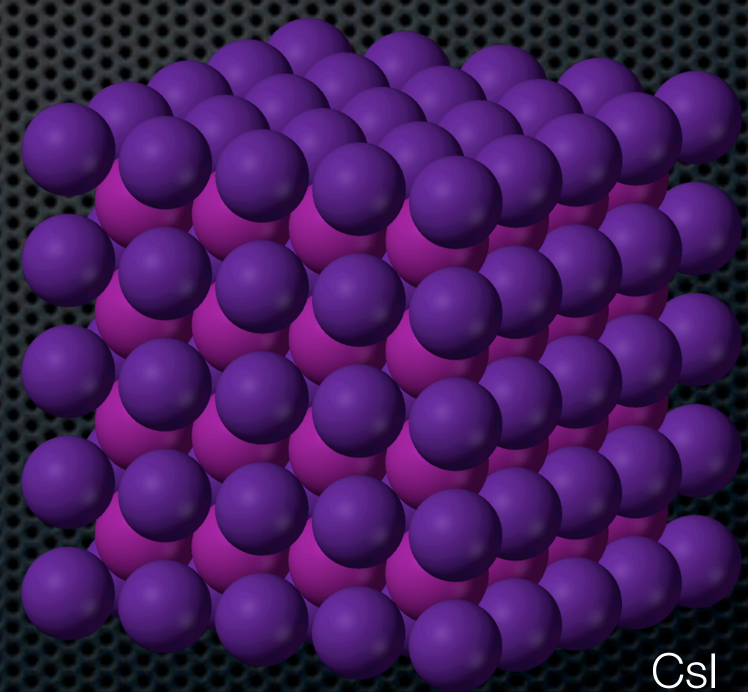

Symmetry (continuous)

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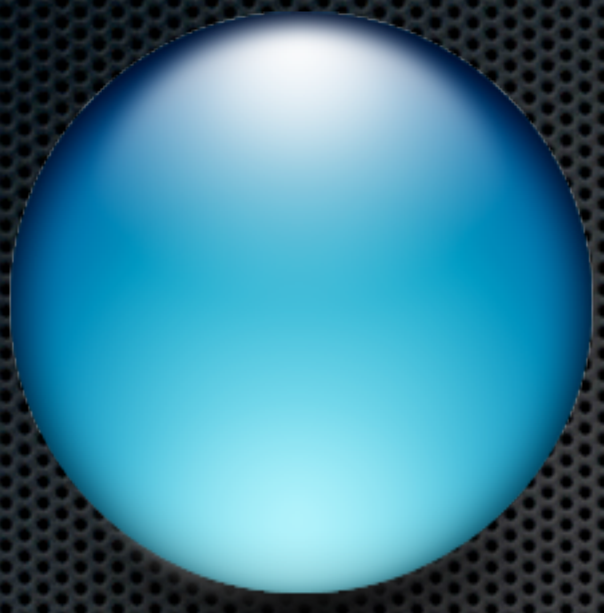
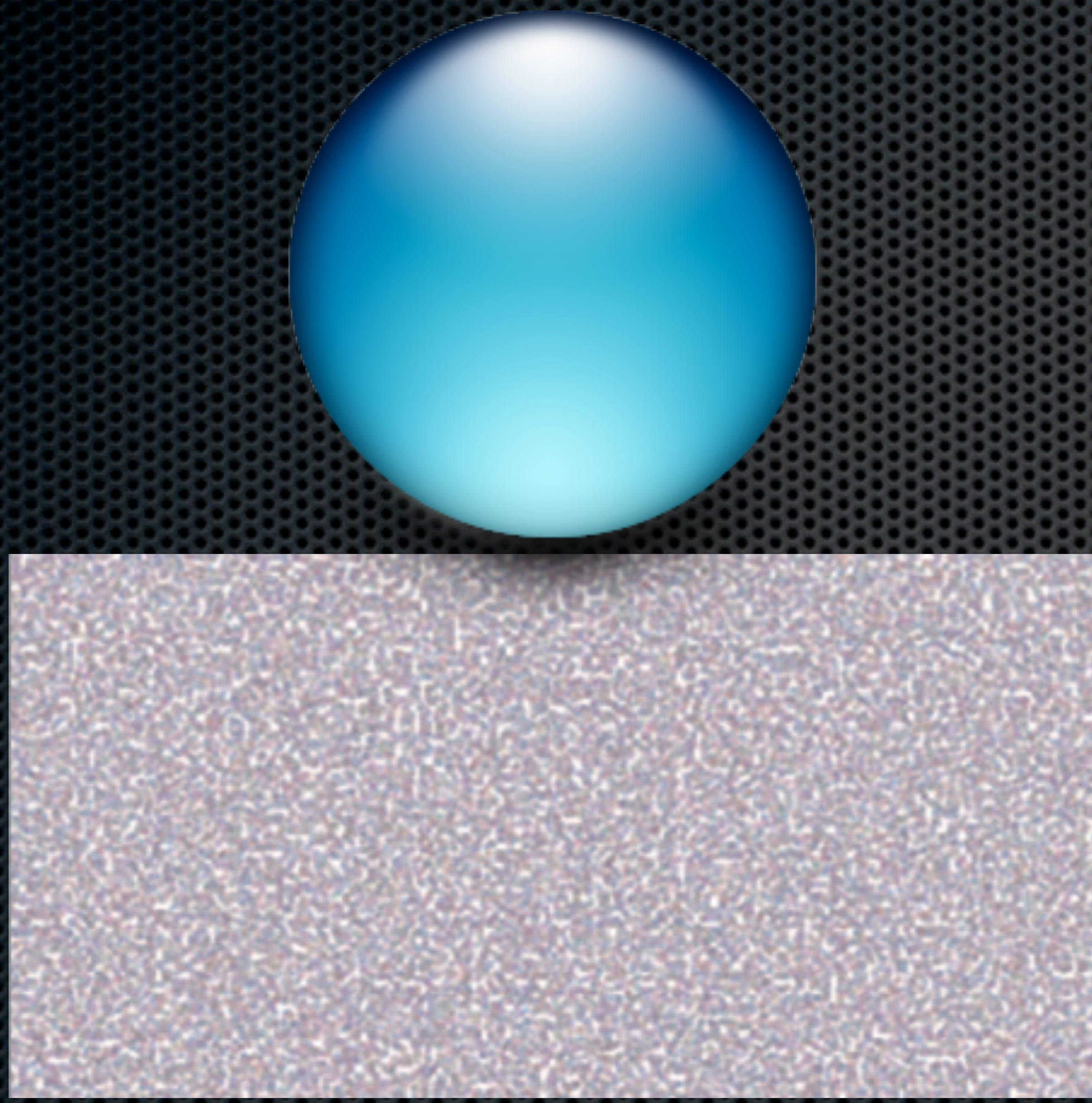
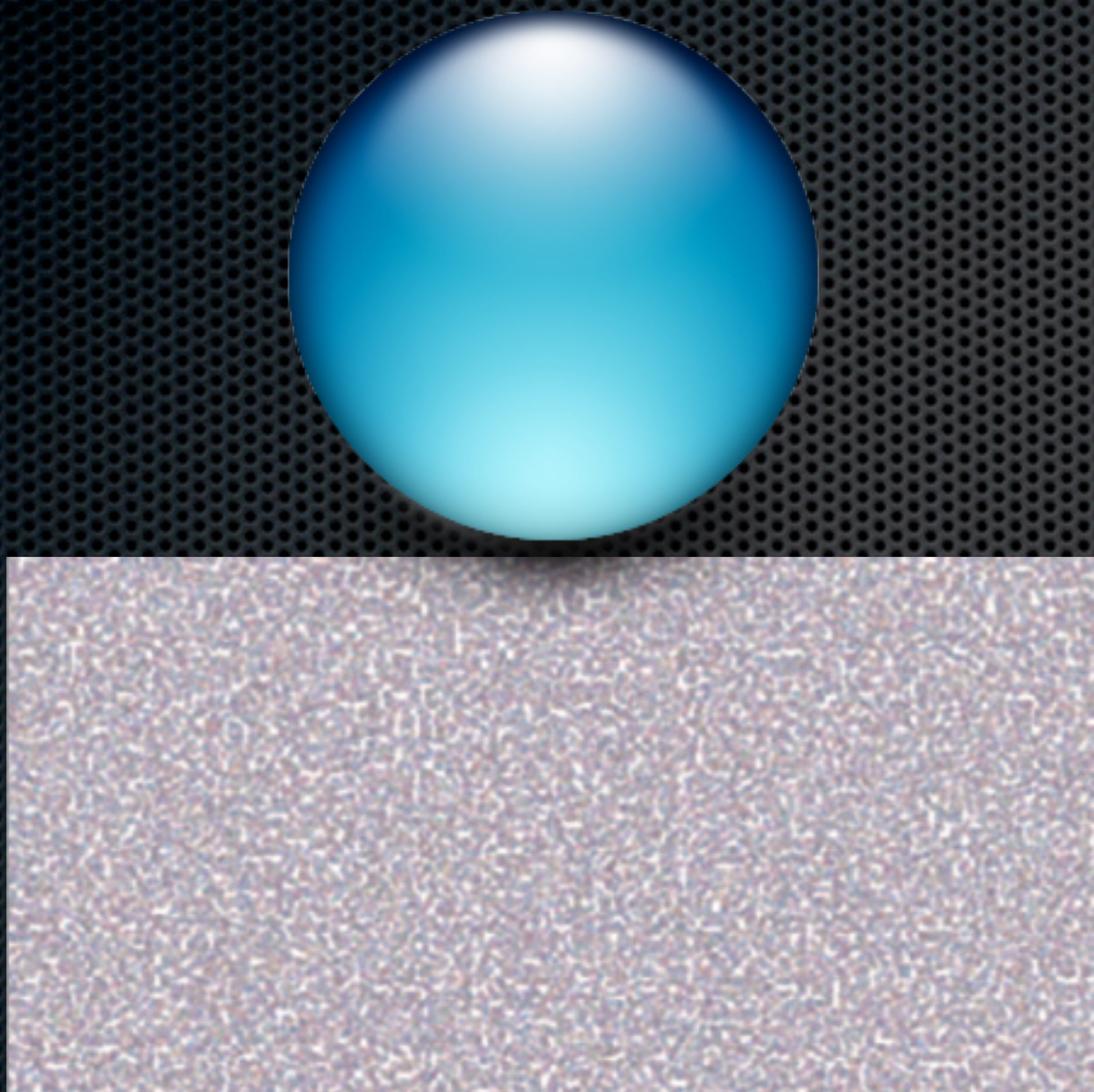
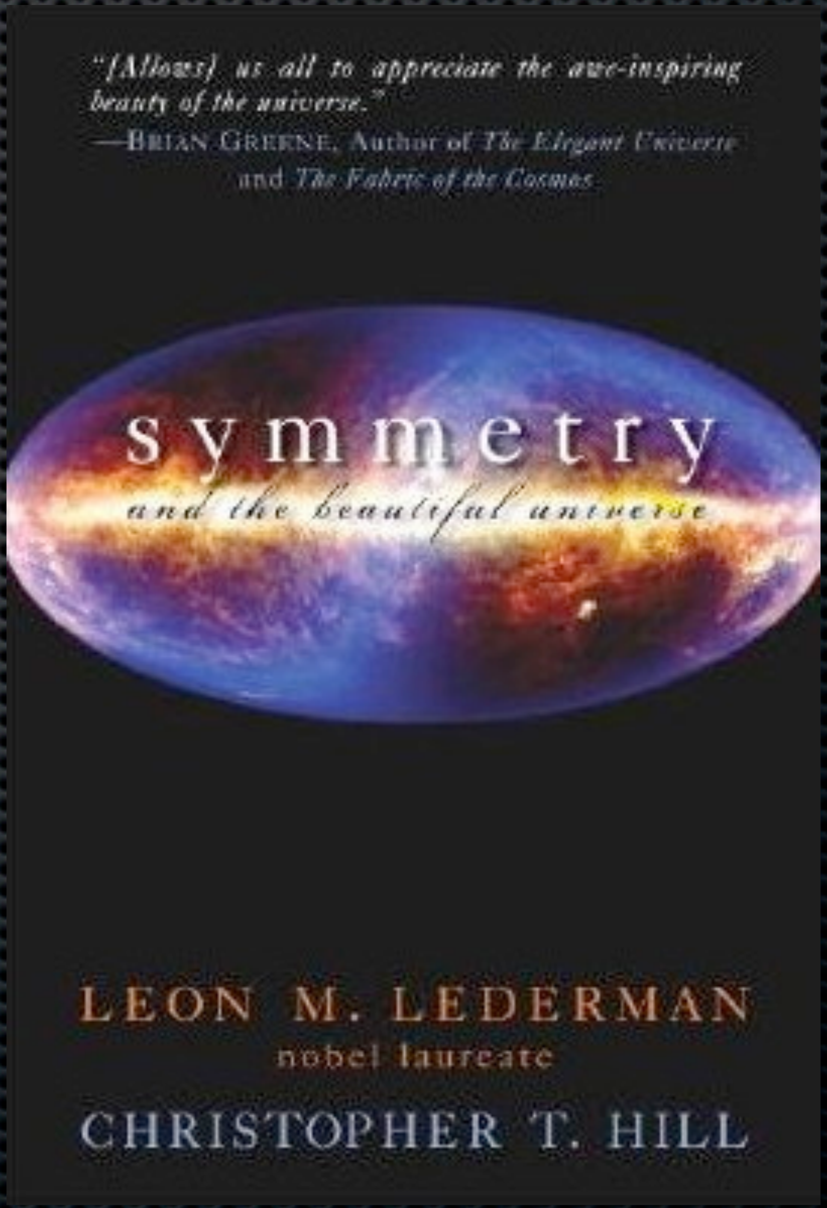


Symmetry (continuous)



Symmetry (continuous)





Symmetry matters.

Broken symmetry is interesting.

BASICS | Natalie Angier

The Mighty Mathematician You've Never Heard Of

Scientists are a famously anonymous lot, but few can match in the depths of her perverse and unmerited obscurity the 20th-century mathematical genius Amalie Noether.

Albert Einstein called her the most "significant" and "creative" female mathematician of all time, and others of her contemporaries were inclined to drop the modification by sex. She invented a theorem that united with magisterial concision two conceptual pillars of physics: symmetry in nature and the universal laws of conservation. Some consider Noether's theorem, as it is now called, as important as Einstein's theory of relativity; it undergirds much of today's vanguard research in physics, including the hunt for the almighty Higgs boson. Yet Noether herself remains utterly unknown, not only to the general public, but to many members of the scientific community as well.

When Dave Goldberg, a physicist at Drexel University who has written about her work, recently took a little "Noether poll" of several dozen colleagues, students and online followers, he was taken aback by the results. "Surprisingly few could say exactly who she was or why she was important," he said. "A few others knew her name but couldn't recall what she'd done, and the majority had never heard of her."

Noether (pronounced NER-ter) was born in Erlangen, Germany, 130 years ago this month. So it's a fine time to counter the chronic neglect and celebrate the life and work of a brilliant theorist whose unshakable number love and irrationally robust sense of humor helped her overcome severe handicaps — first, being female in Germany at a time when most German universities didn't accept female students or hire female professors, and then being a Jew-

RS

GROUNDBREAKING Emmy Noether's theorem united two pillars of physics: symmetry in nature and the universal laws of conservation.

symmetry in nature, some predictability or homogeneity of parts, you'll find lurking in the background a corresponding conservation — of momentum, electric charge, energy or the like. If a bicycle wheel is radially symmetric, if you can spin it on its axis and it still looks the same in all directions, well, then, that symmetric translation must yield a corresponding conservation. By applying the principles and calculations embodied in Noether's theorem, you'll see it's angular momentum, the Newtonian impulse that keeps bicyclists upright and on the move.

Some of the relationships to pop out of the theorem are startling, the most profound one linking time and energy. Noether's theorem shows that a symmetry of time — like the fact that whether you throw a ball in the air tomorrow or make the same toss next week will have no effect on the ball's trajectory — is directly related to the conservation of energy, our old homily that energy can be neither created nor destroyed but merely changes form.

The connections that Noether forged are "critical" to modern physics, said Lisa Randall, a professor of theoretical particle physics and cosmology at Harvard. "Energy, momentum and other quantities we take for granted gain meaning and even greater value when we understand how these quantities follow from symmetry in time and space."

Dr. Randall, the author of the newly published "Knocking on Heaven's Door," recalled the moment in college when she happened to learn that the author of Noether's theorem was a she. "It was striking and even exciting and inspirational," Dr. Randall said, admitting, "I was surprised by my reaction."

For her part, Noether left little record

Symmetries & conservation laws

Spatial translation	*Momentum*
Time translation	*Energy*
Rotational invariance	*Angular momentum*
QM phase	*Charge*

Symmetries of laws

need not imply

symmetries of outcomes.

symmetries of laws $\not\Rightarrow$ symmetries of outcomes

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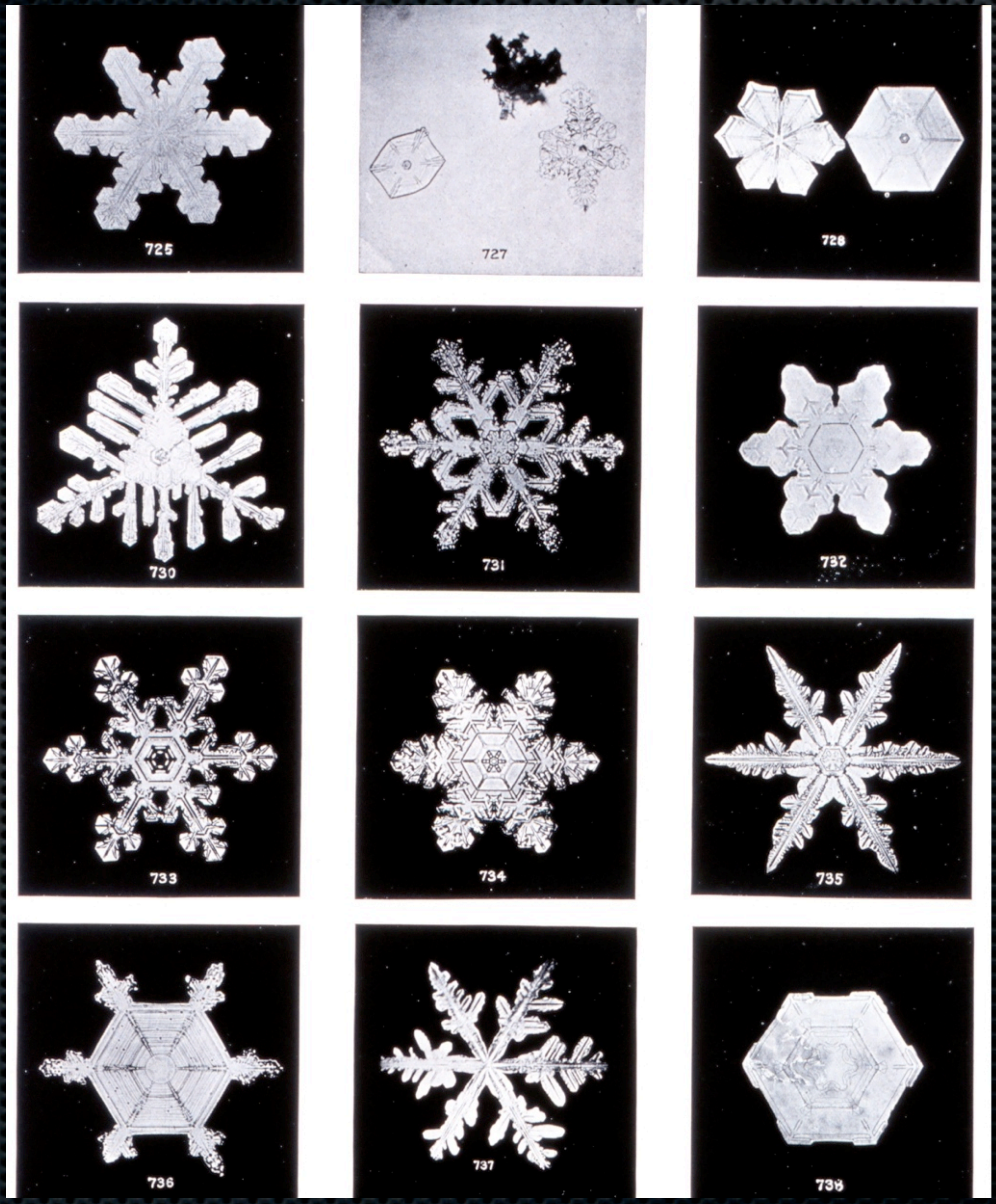
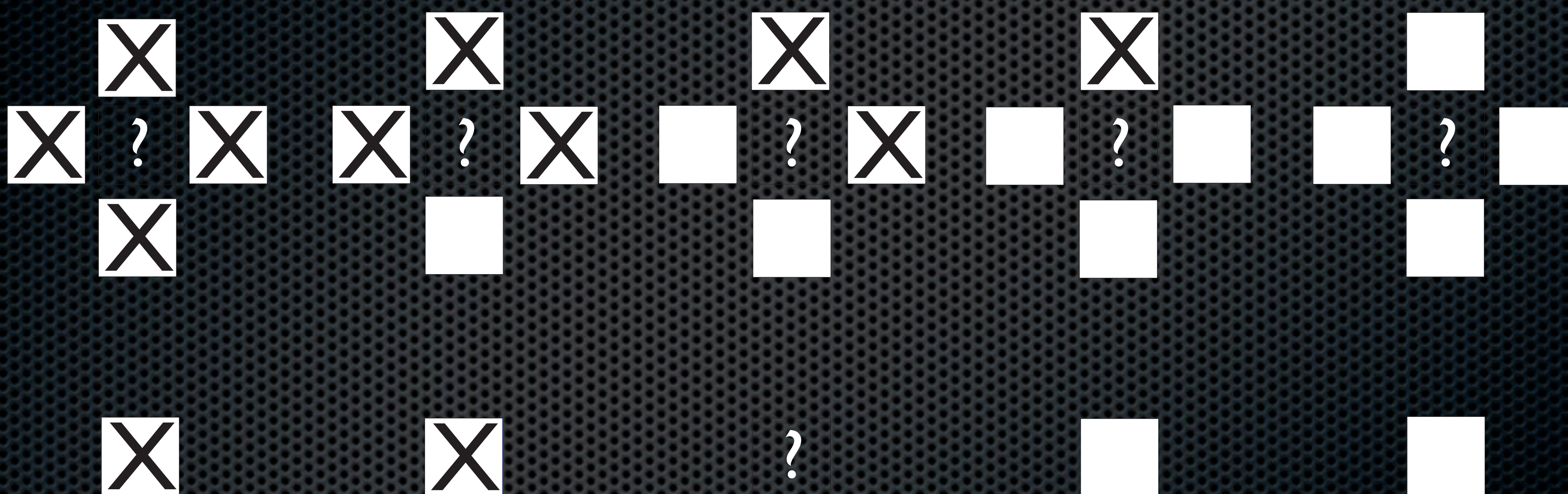


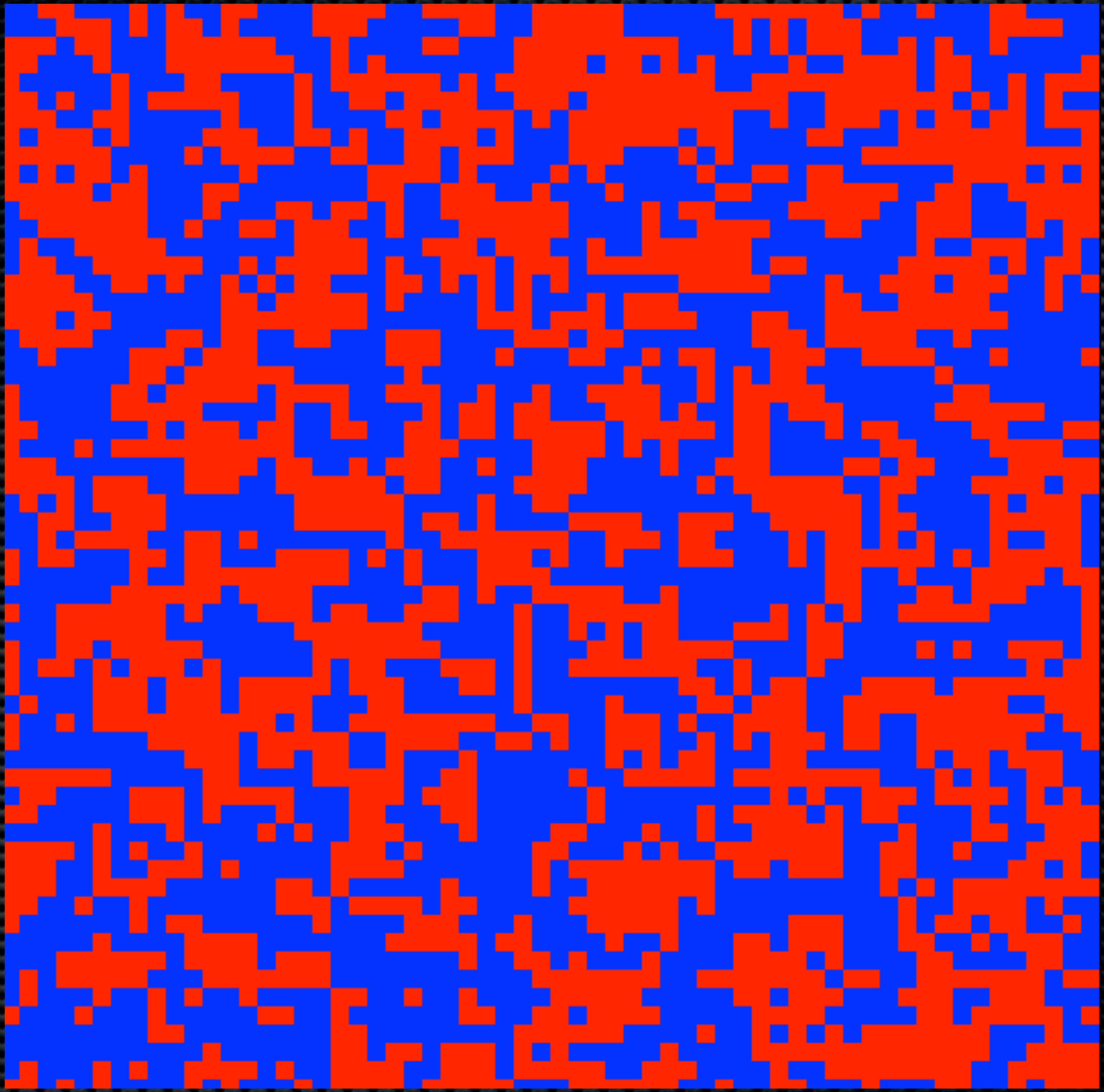
Studies among the Snow Crystals ... by Wilson Bentley, via NOAA Photo Library

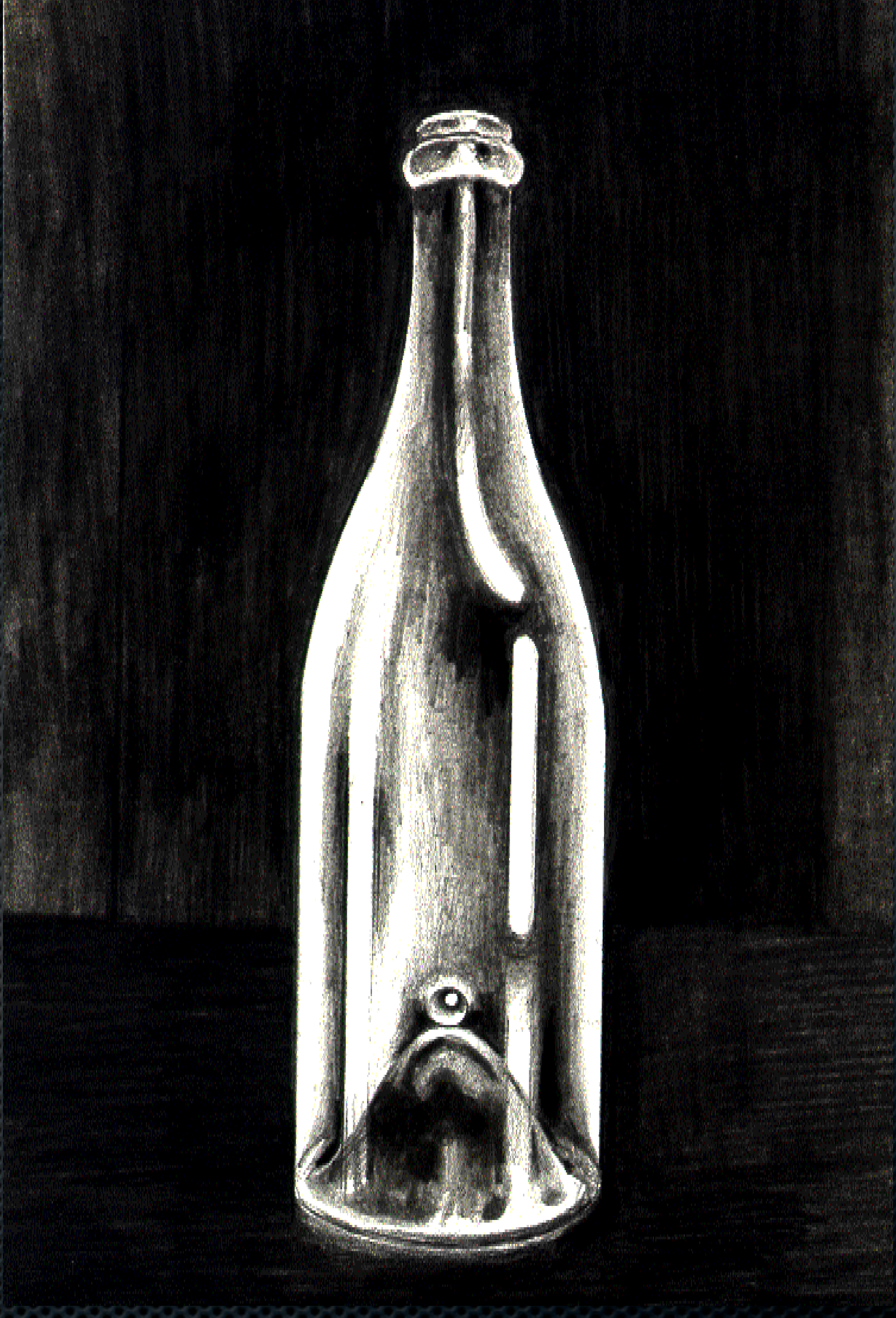

IN GOD WE TRUST
LIBERTY
2010
S

X


UNITED STATES OF AMERICA
E·PLURIBUS
·UNUM·
ONE CENT

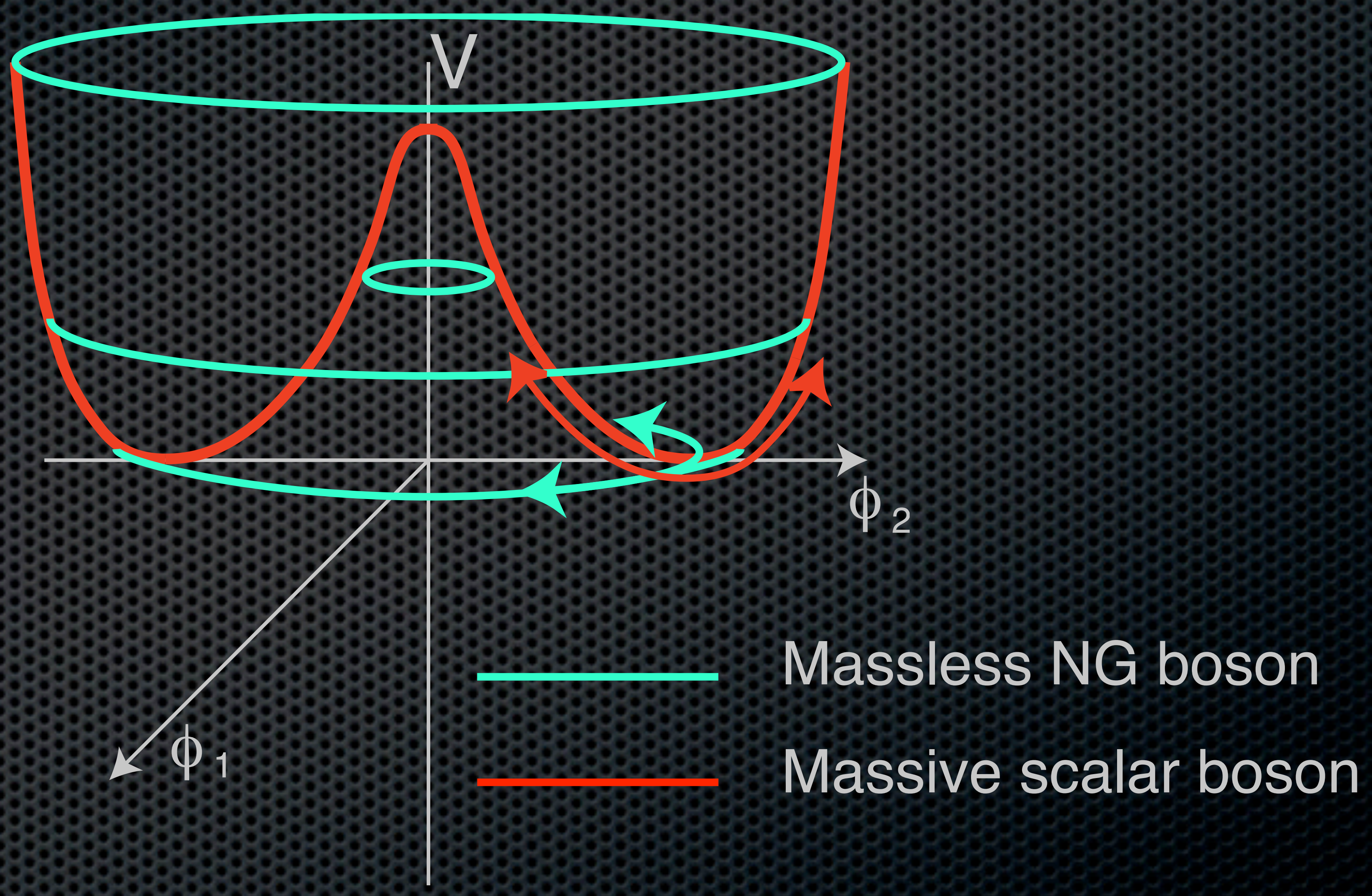




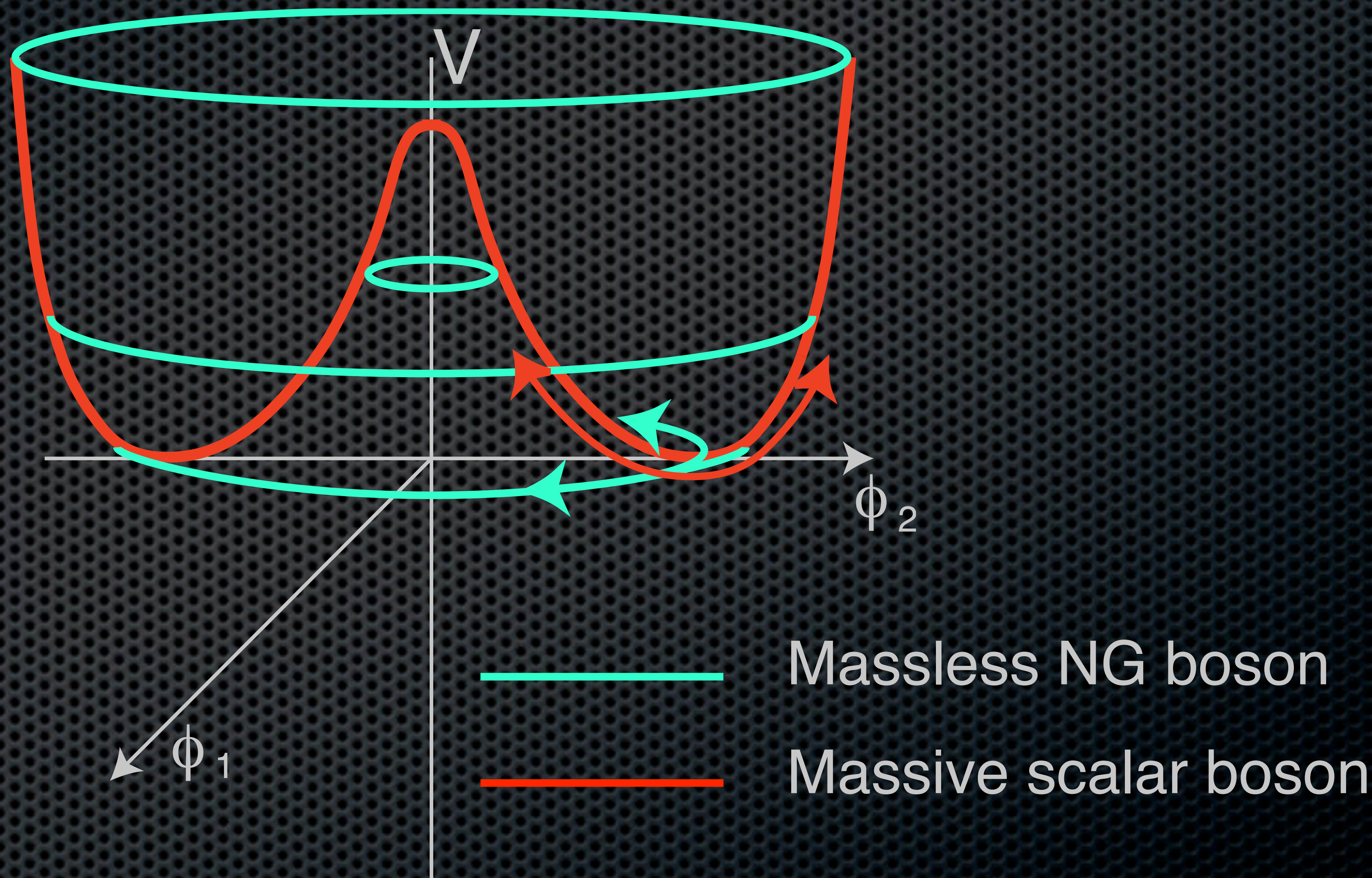


Continuum of degenerate vacua

Nambu–Goldstone bosons

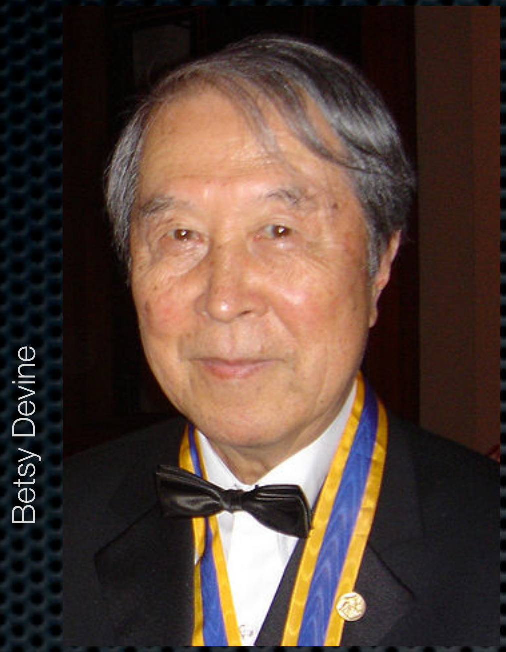


Nambu–Goldstone bosons



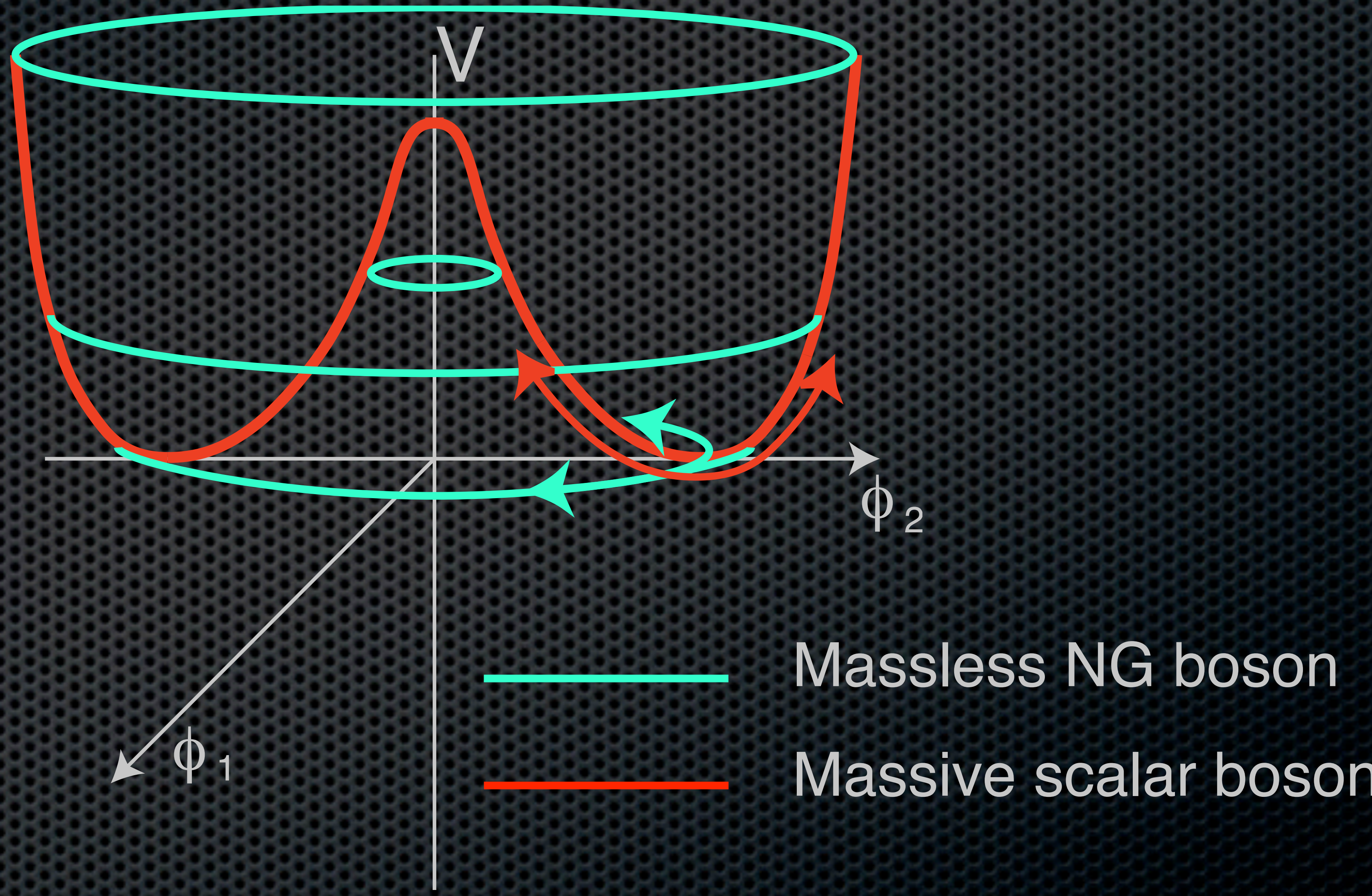
NGBs as spin waves, phonons, pions, …

Nambu–Goldstone bosons



Yoichiro Nambu

Jeffrey Goldstone

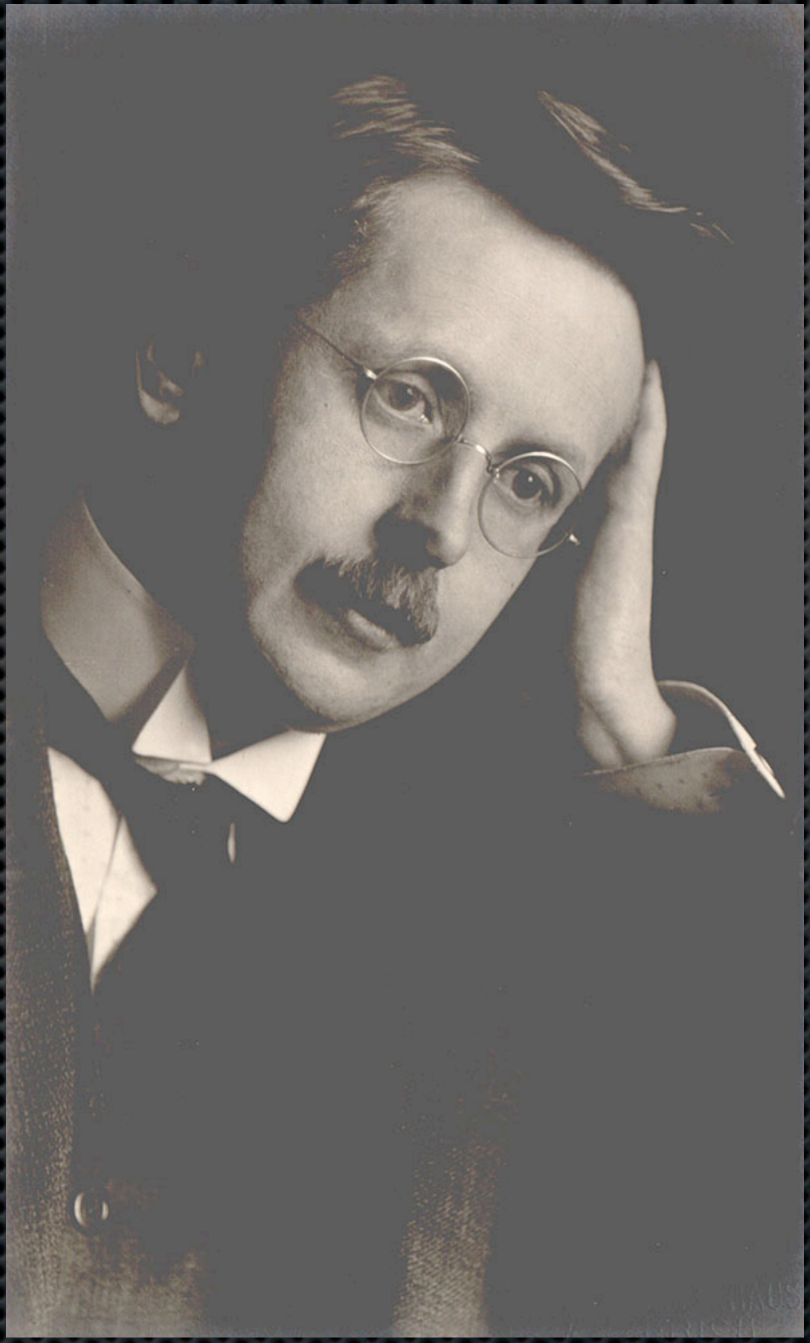


NGBs as spin waves, phonons, pions, …

Form follows function.

Louis Sullivan (1896)

Function follows form. I



Hermann Weyl (1918, 1929)

Complex phase in QM

Complex phase in QM

Global: free particle

Complex phase in QM

Global: free particle

Local: interactions

Maxwell’s equations; QED


James Clerk Maxwell (1861/2)

massless photon
coupled to conserved charge

no impediment to electron mass

Maxwell's equations; QED

James Clerk Maxwell (1861/2)

massless photon
coupled to conserved charge

no impediment to electron mass

(e_L & e_R have same charge)

Function follows form. II


Robert Mills (1954) C. N. Yang

Can one choose independently
at each point in spacetime
the convention to name
proton and neutron?

Local isospin symmetry implies
3 massless gauge bosons
coupled to isospin

no impediment to nucleon mass

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Local isospin symmetry implies
3 massless gauge bosons ☹
coupled to isospin

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(N_L & N_R have same isospin)

Might hiding symmetry help?

Seems to add massless NGBs

to massless gauge bosons

Goldstone theorem proved
with ever-increasing rigor

Might hiding symmetry help?

Seems to add massless NGBs ☹

to massless gauge bosons ☹

Goldstone theorem proved
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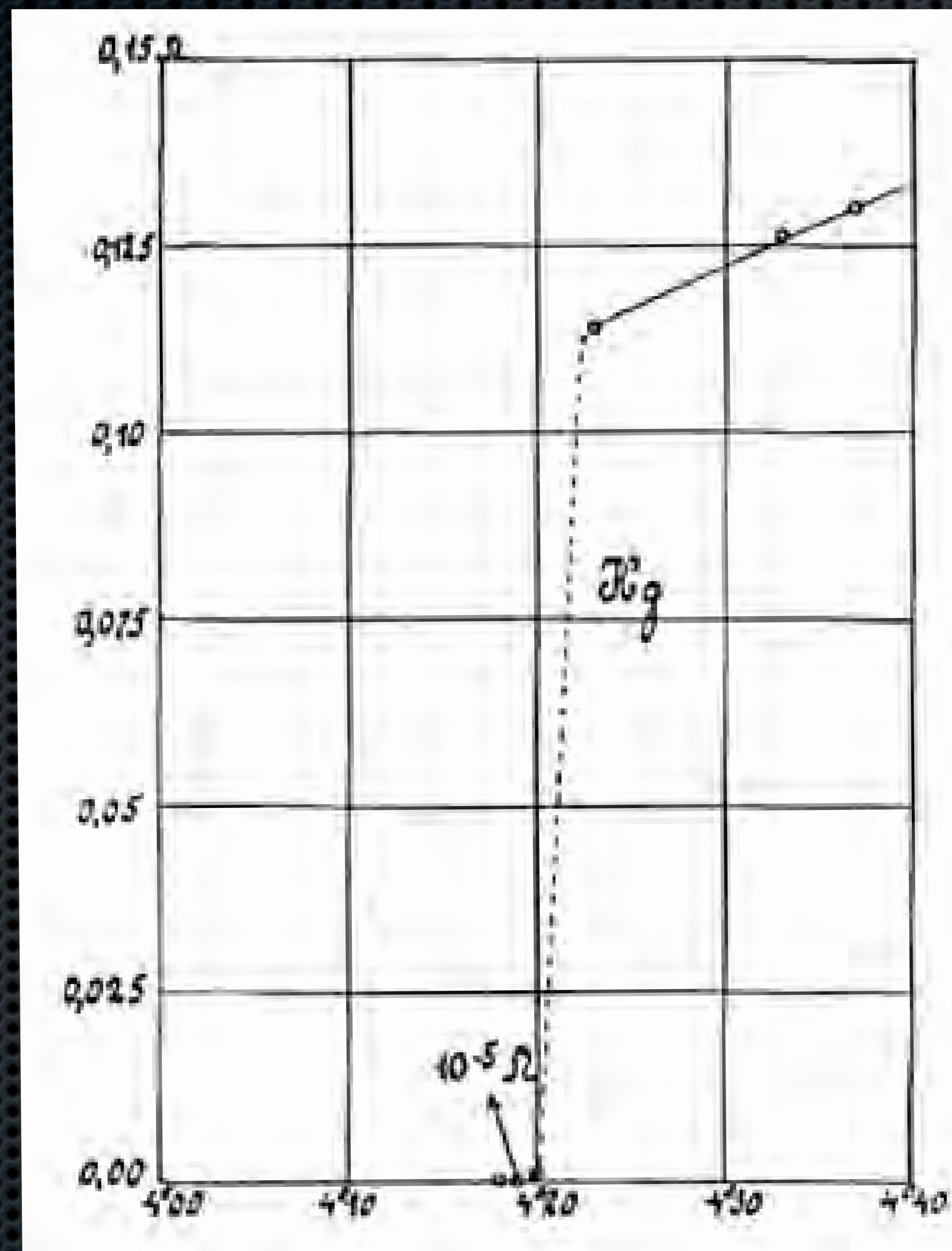
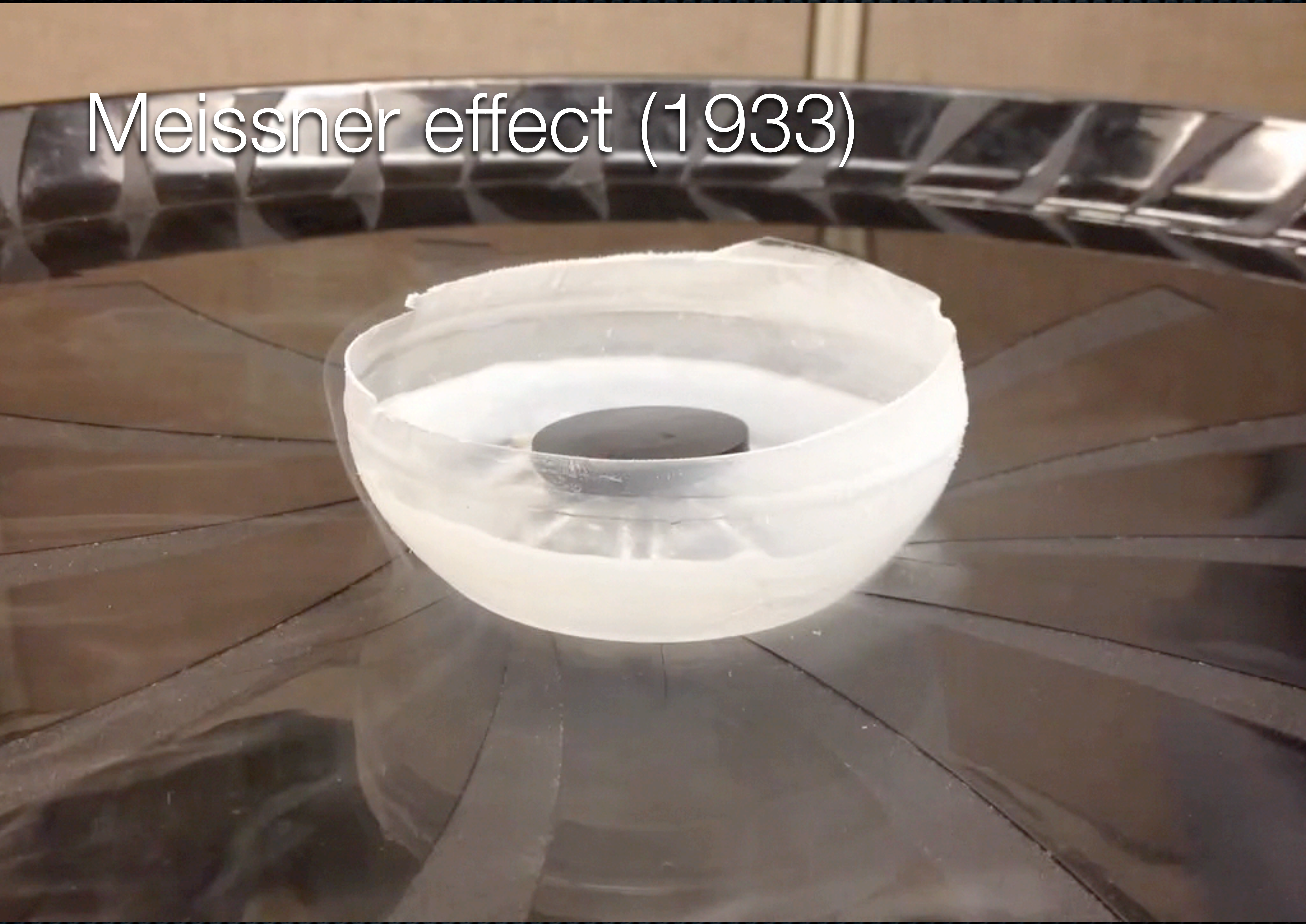
Superconductivity (1911)

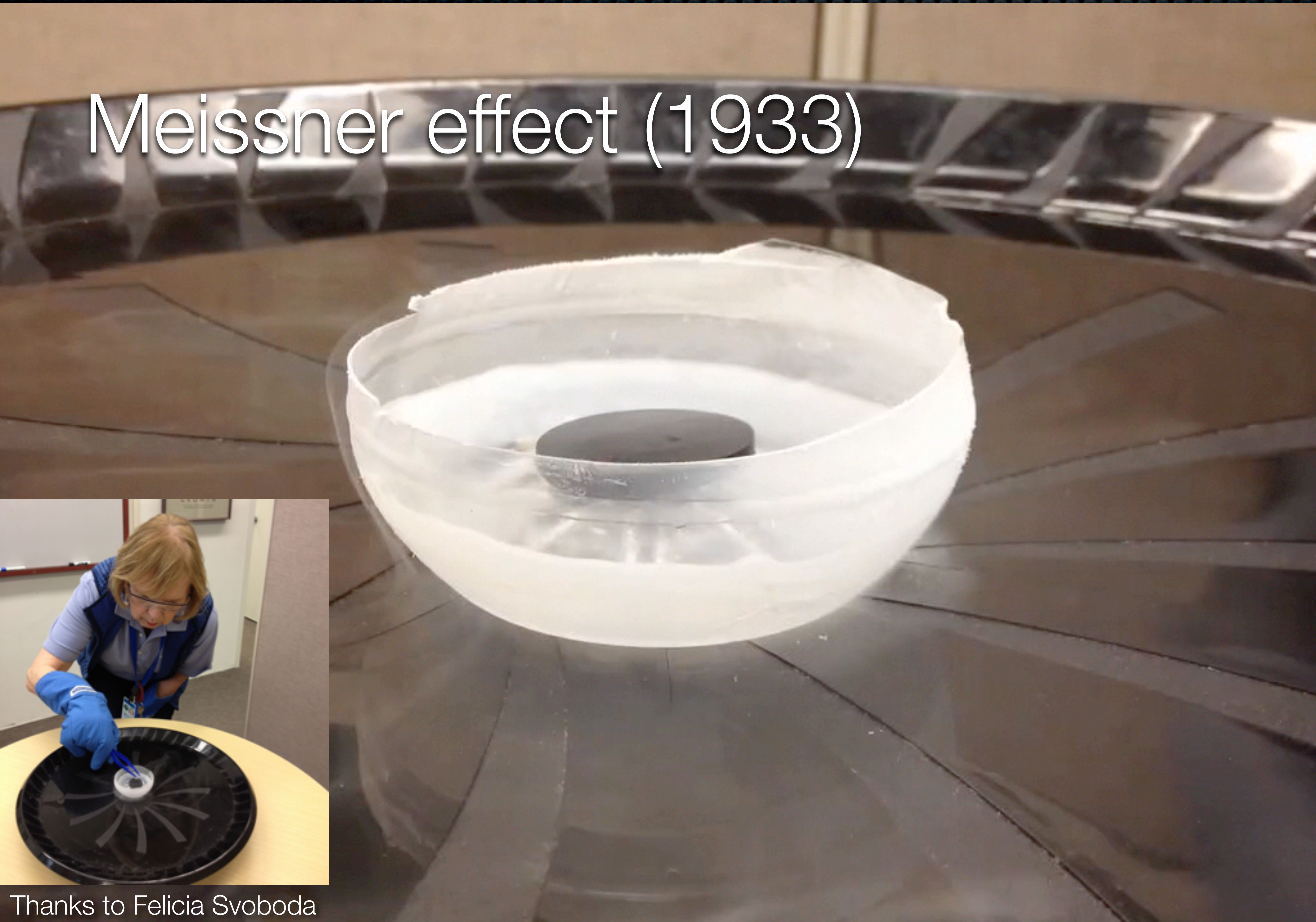


Heike Kamerlingh Onnes

Meissner effect (1933)



Meissner effect (1933)



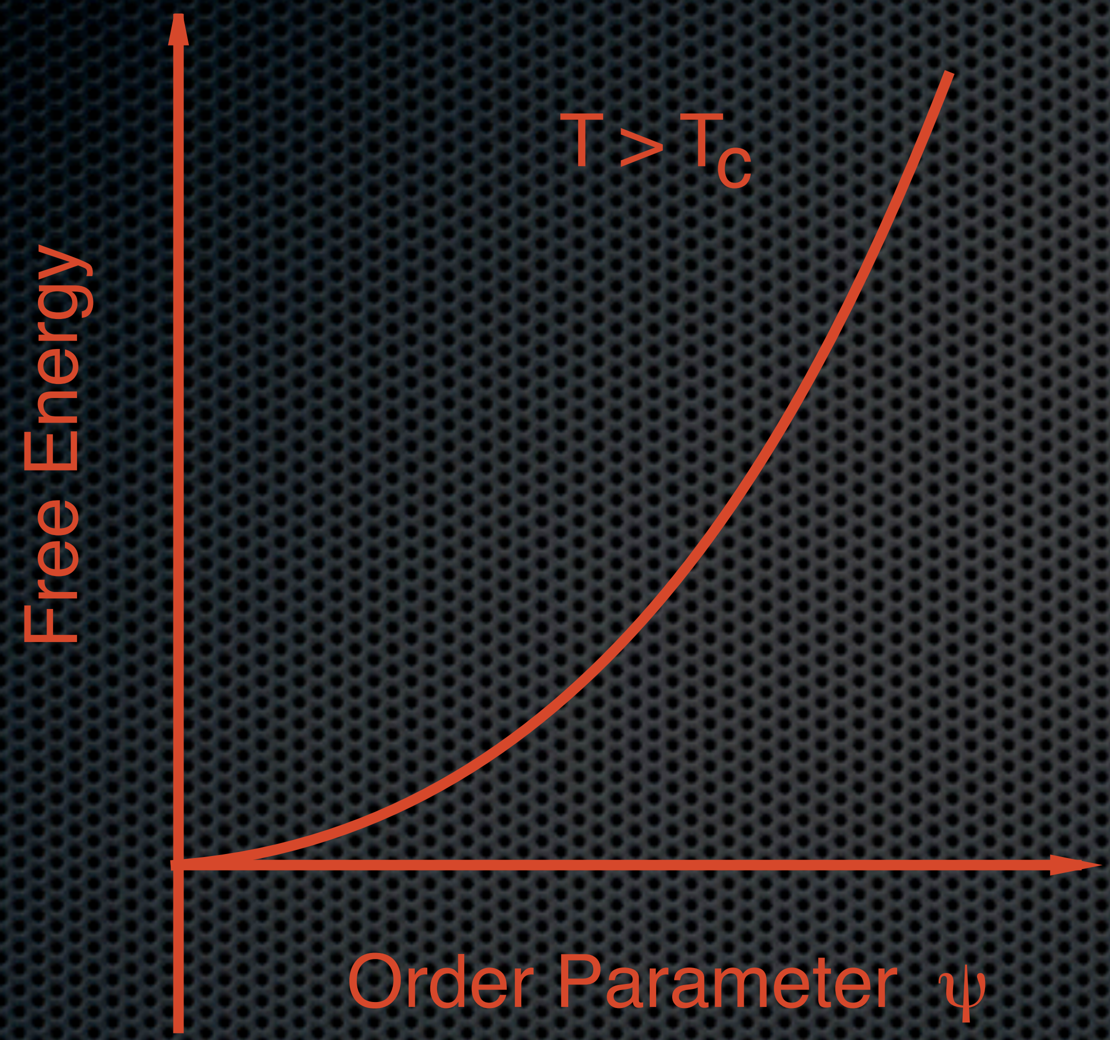
Thanks to Felicia Svoboda

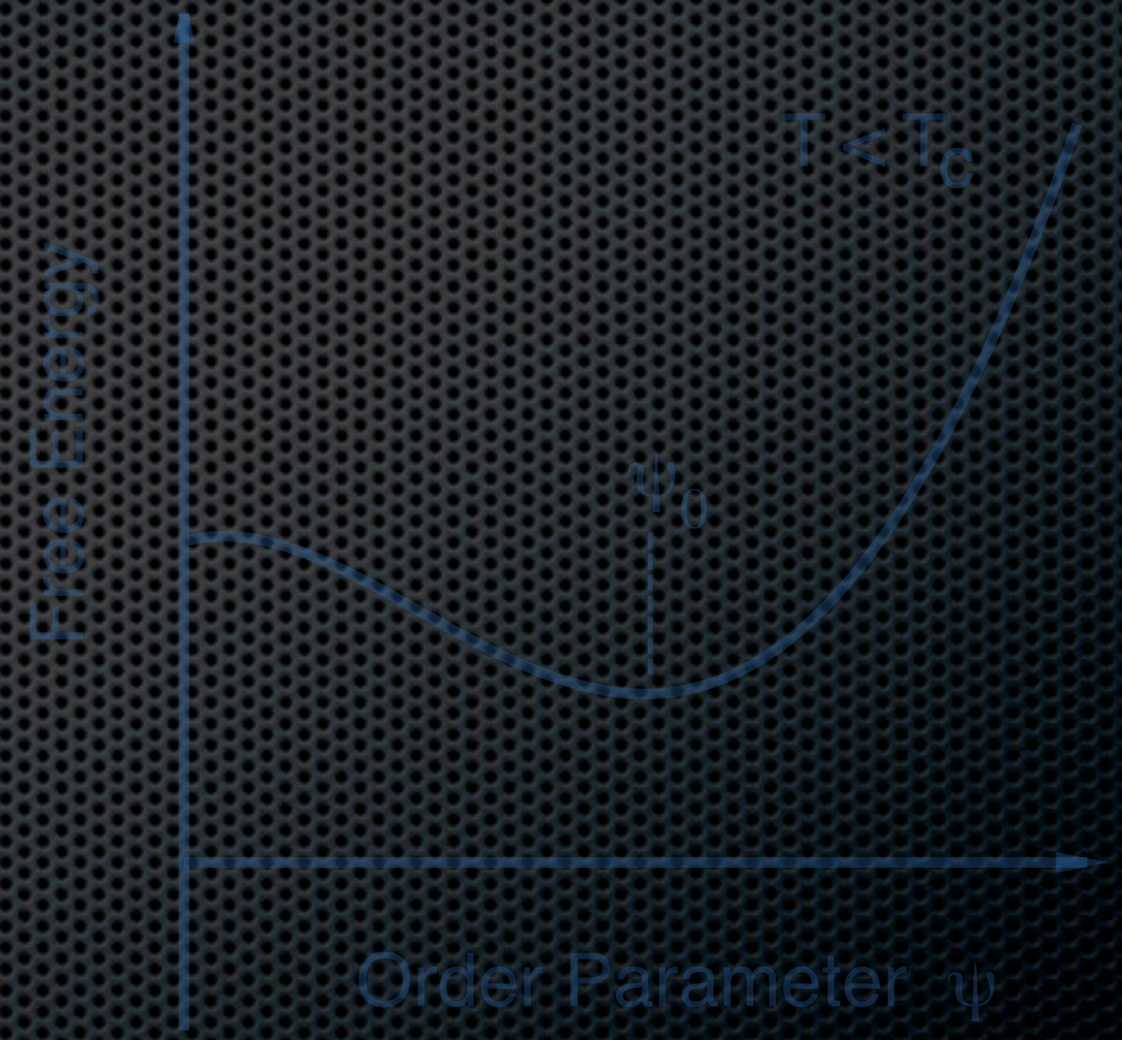
Magnetic fields excluded

Walther Meißner   Robert Ochsenfeld

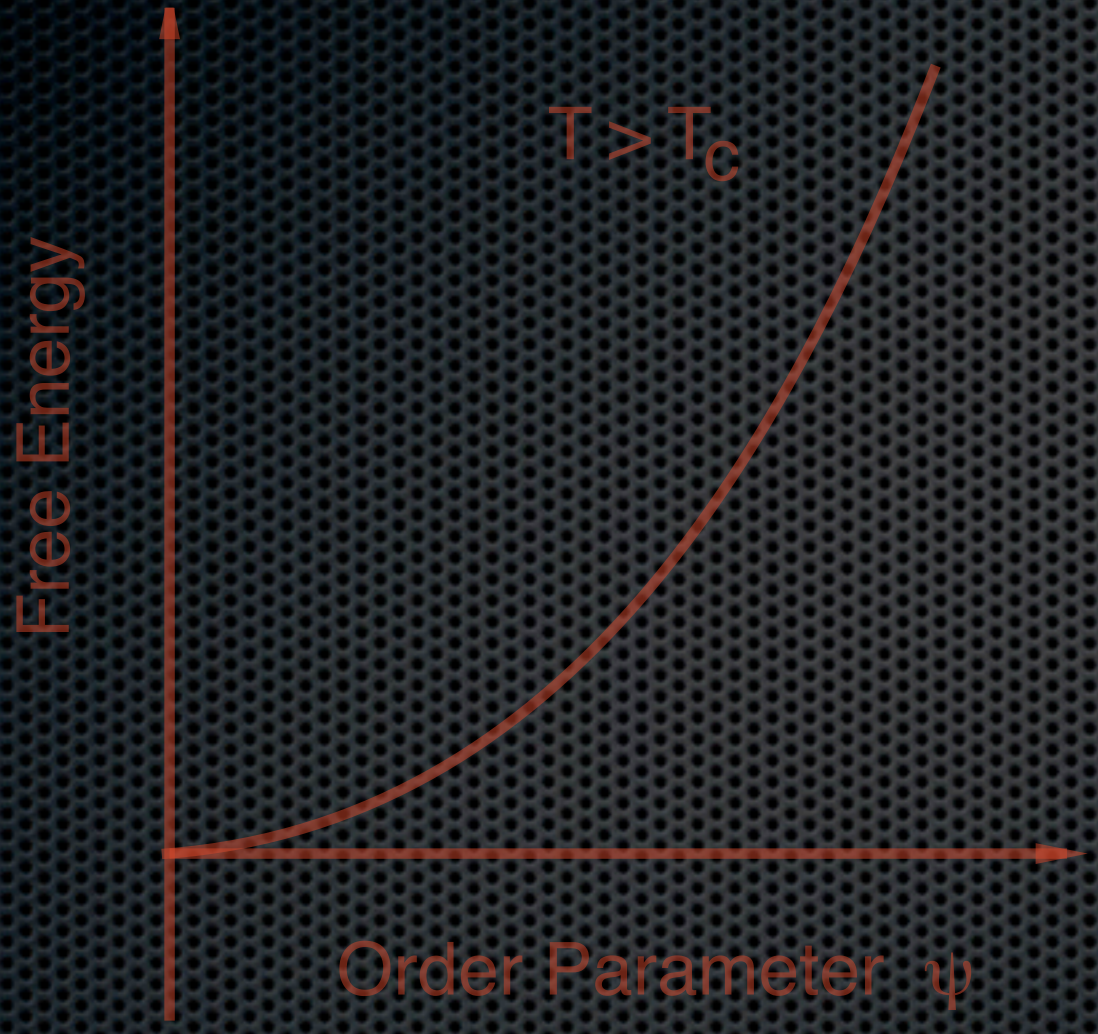
Pb: 40 nm penetration

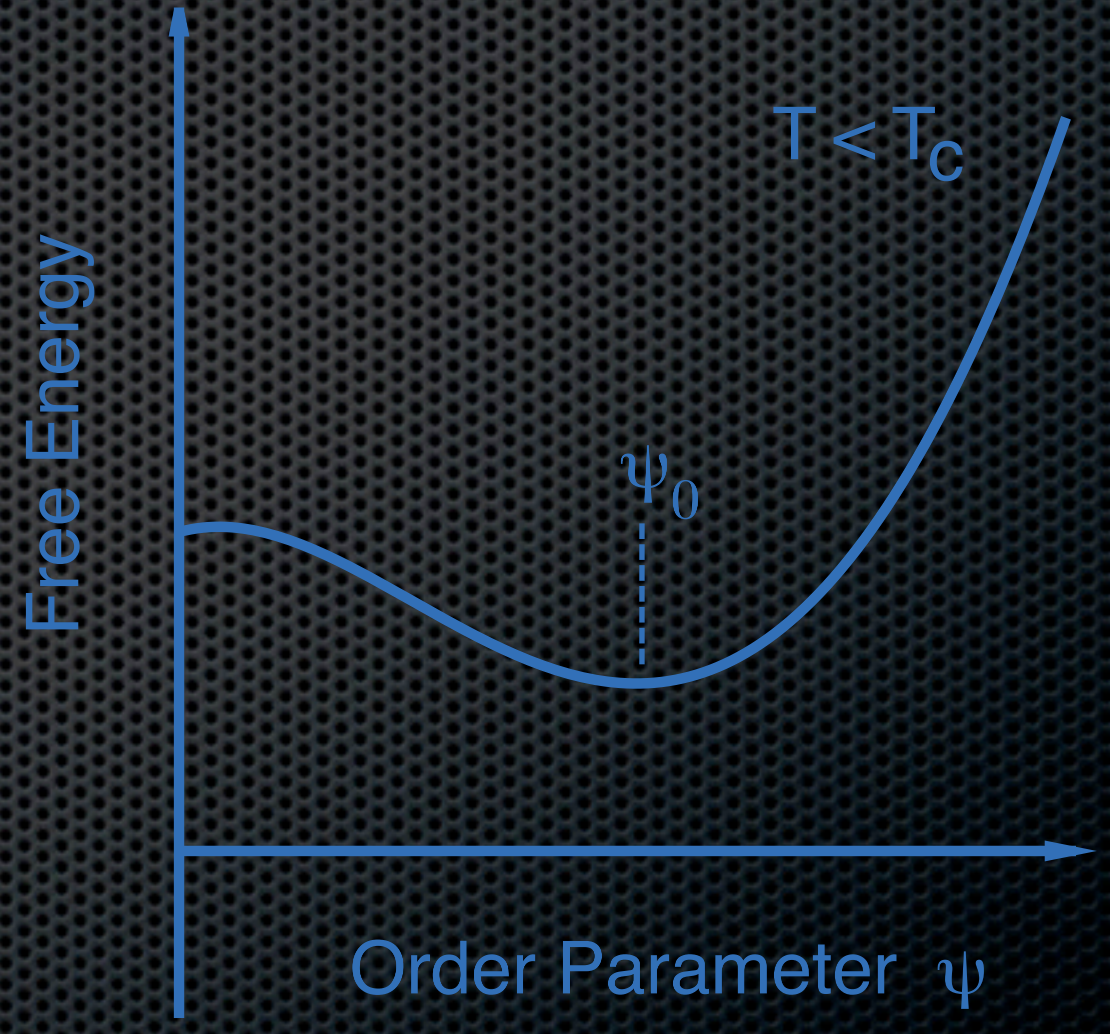
Ginzburg–Landau model (1950)



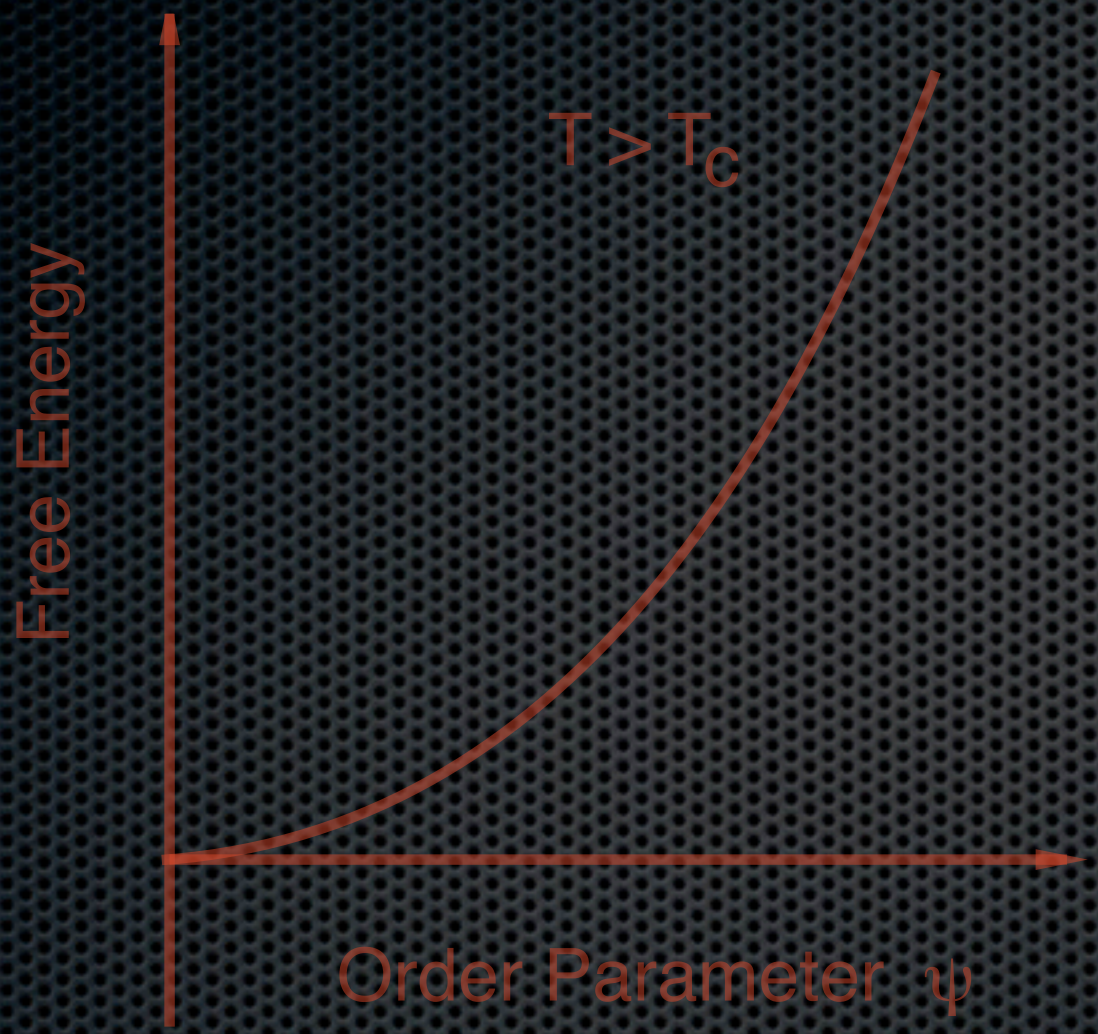


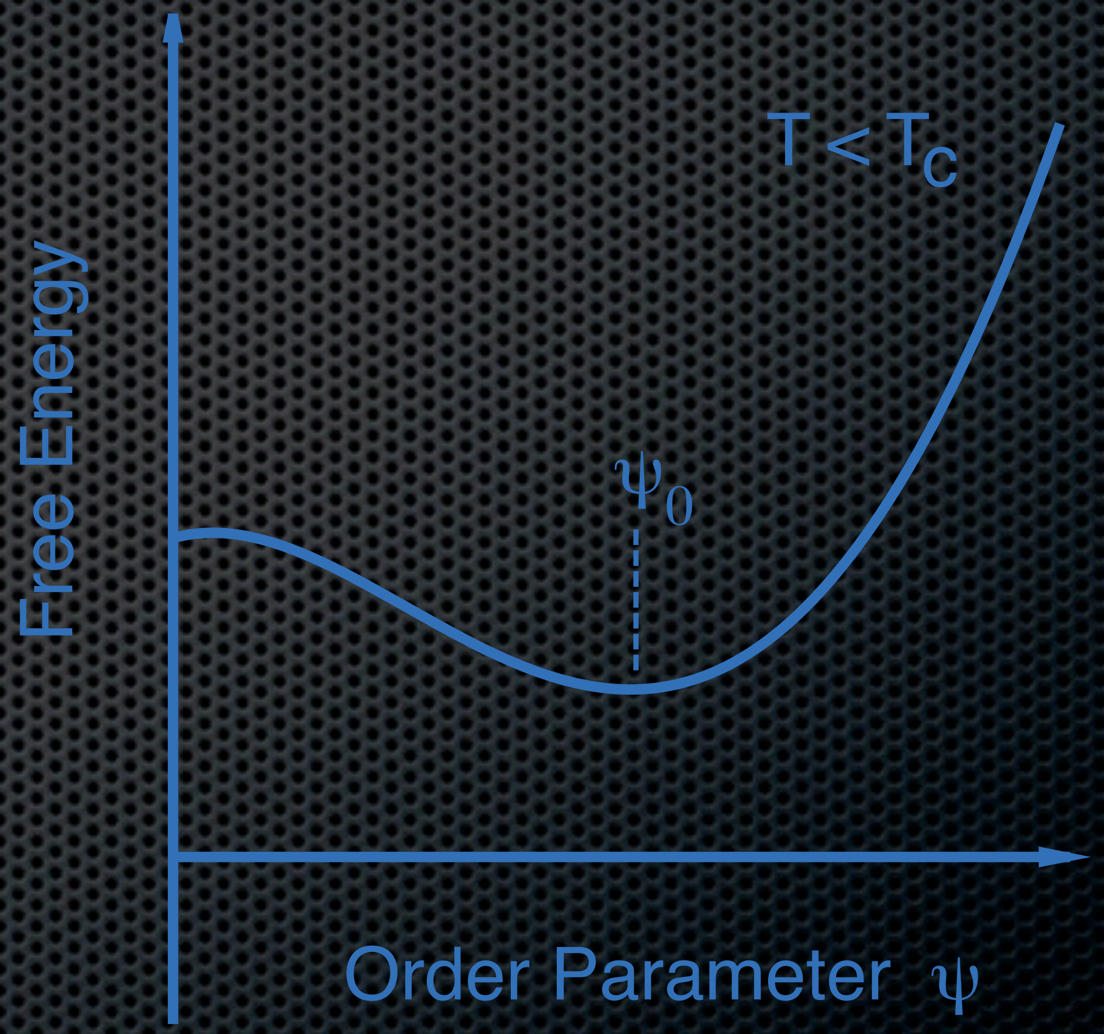
Ginzburg–Landau model (1950)





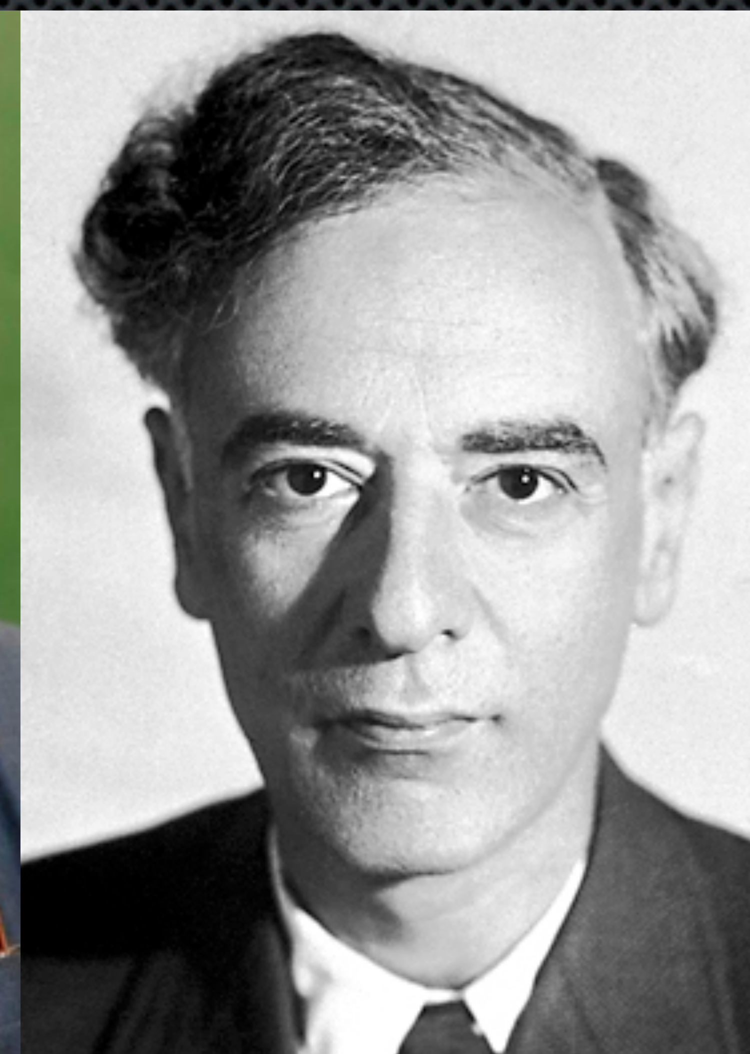
Ginzburg–Landau model (1950)





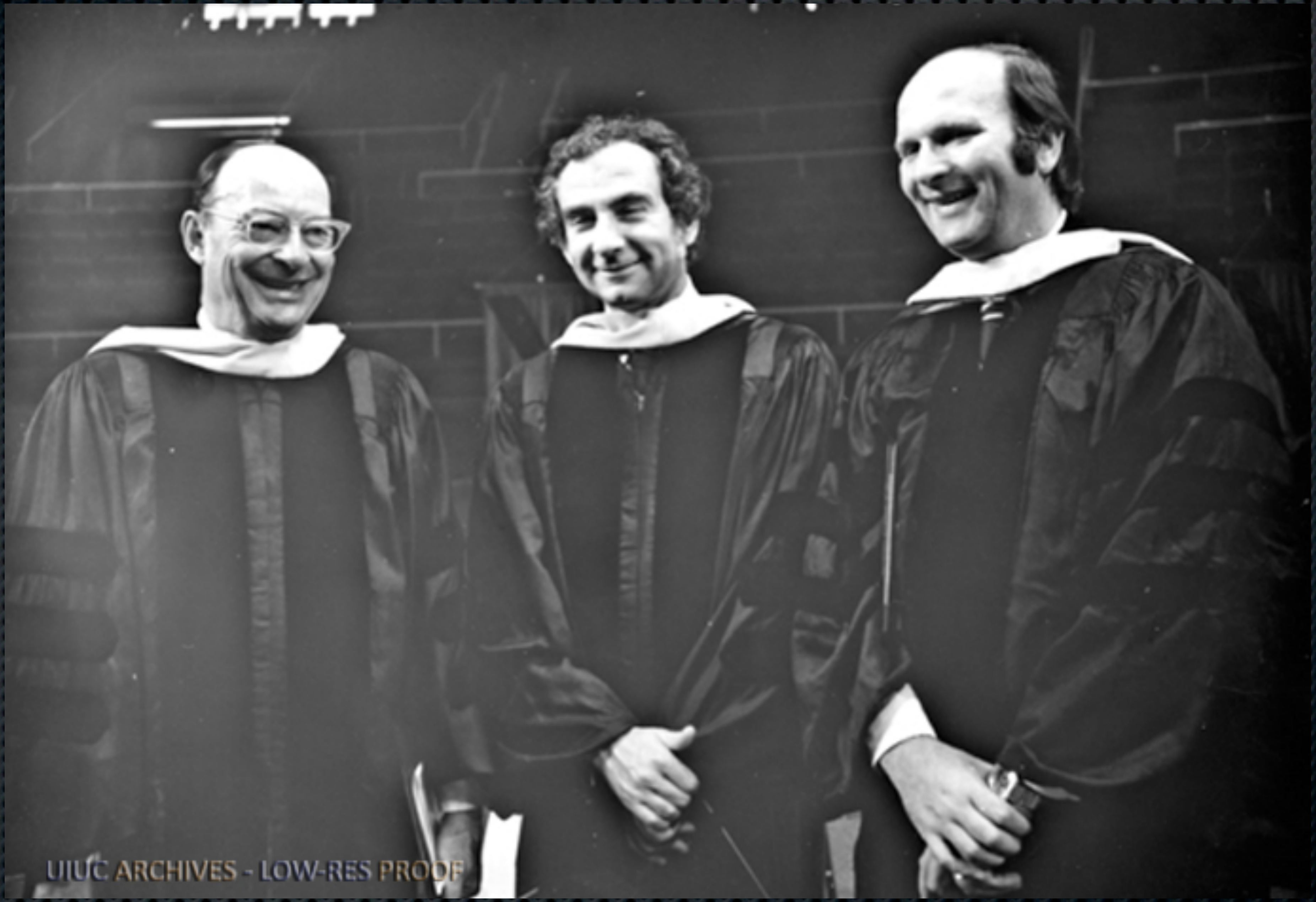
Photon acquires mass in superconductor

Vitaly Ginzburg



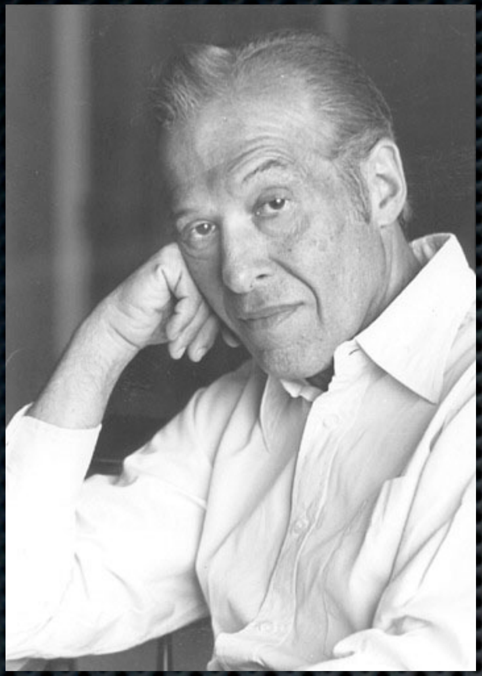
Lev Landau

BCS theory (1957)



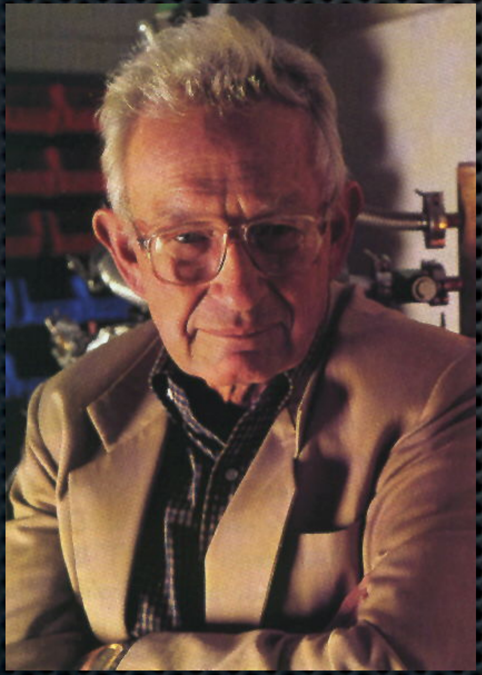
John Bardeen Leon Cooper Robert Schrieffer

Some hints



Julian Schwinger

(1962) Photon can acquire mass in 1+1-dimensional QED



Phil Anderson

(1963) Superconductor: massive photon, hidden gauge symmetry. Model for strong interactions?

Spontaneous symmetry breaking


Higgs Kibble Guralnik Hagen Englert Brout†

1964– : Goldstone theorem doesn't apply to gauge theories!

Each would-be massless NGB joins with a would-be massless gauge boson to form a massive gauge boson.

Simplest example: Abelian Higgs model
= Ginzburg–Landau in relativistic notation

Yields massive photon

+

a massive scalar particle

"Higgs boson"

Simplest example: Abelian Higgs model
= Ginzburg–Landau in relativistic notation

Yields massive photon

+

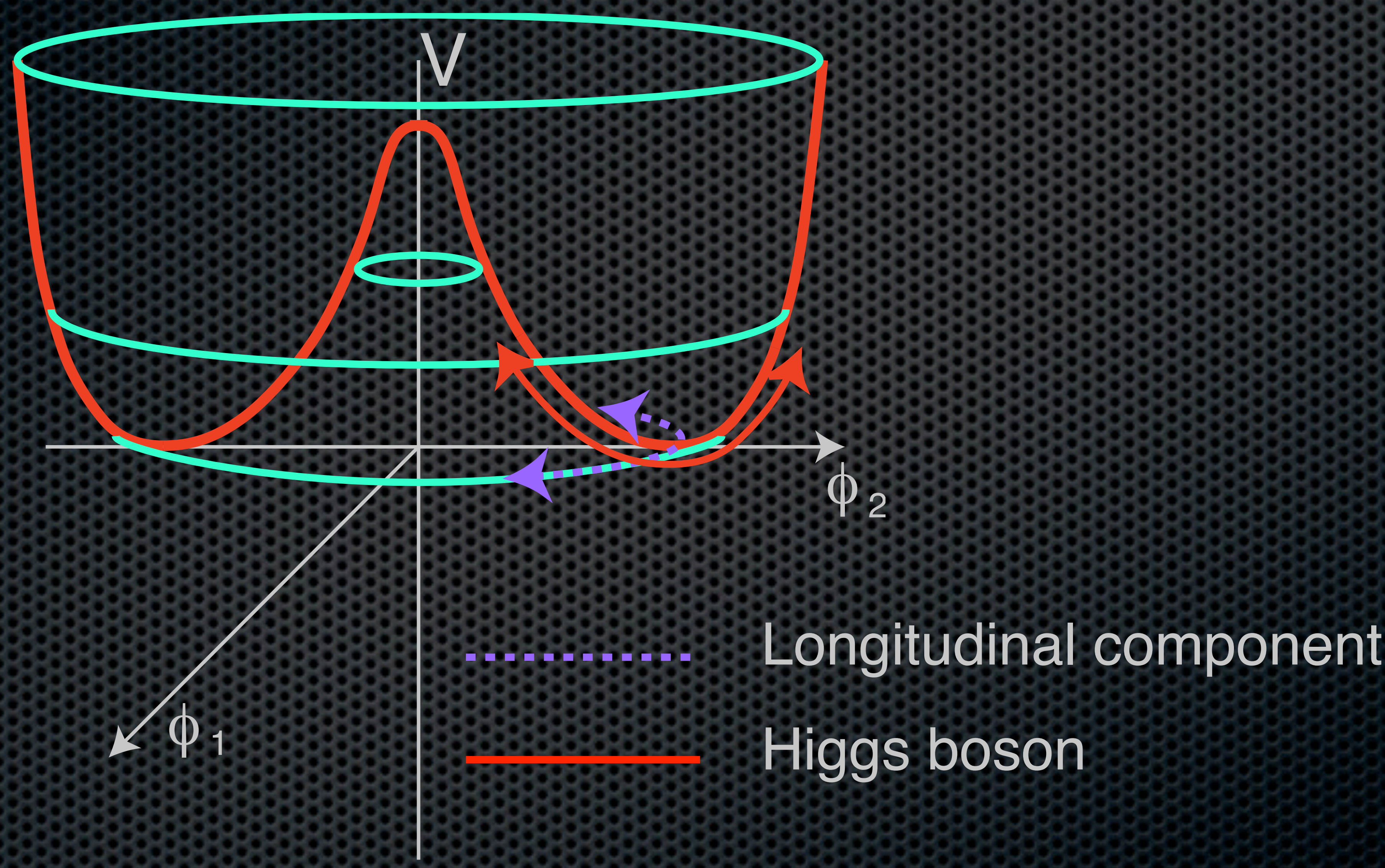
a massive scalar particle

"Higgs boson"

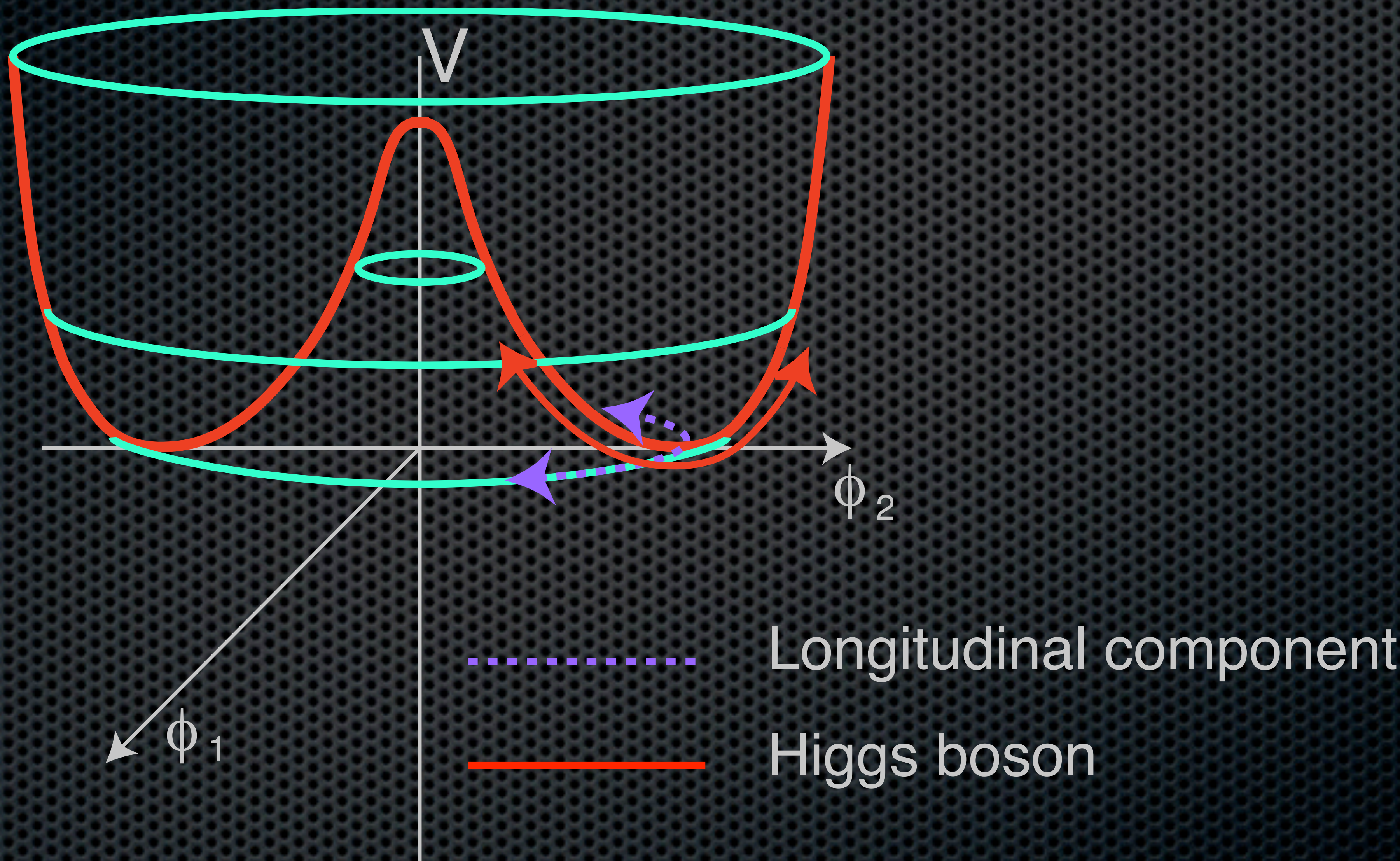
No mention of weak interactions.

No question of fermion masses
(not an issue for Yang–Mills theory).

Spontaneously broken gauge theory



Spontaneously broken gauge theory



1981: massive collective mode (Raman scattering in $NbSe_2$)

Many fingers in the pie ....

"Higgs fields", for example, are just the scalar fields of a linear sigma model, which was discussed in 1960 by Gell-Mann and Lévy[1] but had been introduced three years earlier by Schwinger[2]. And "the Higgs mechanism" was first described by Philip Anderson[3]: perhaps it should be called "the ABEGHHK'tH.... mechanism" after all the people (Anderson, Brout, Englert, Guralnik, Hagen, Higgs, Kibble, 't Hooft) who have discovered or rediscovered it! However, I do accept responsibility for the Higgs boson; I believe that I was the first to draw attention to its existence in spontaneously broken gauge theories[4].

Peter Higgs, *50 Years of Weak Interactions,* Wingspread (1984)

The Schwinger-Anderson-Englert-Brout-Higgs-Guralnik-Hagen-Kibble ~~boson~~ mechanism

Ian Aitchison, “The unbearable heaviness of being,” *Physics World* (July 1989)

What of Yang–Mills (isospin) theory?

After SSB, still not the theory of nuclear forces

Right idea, wrong symmetry, wrong constituents

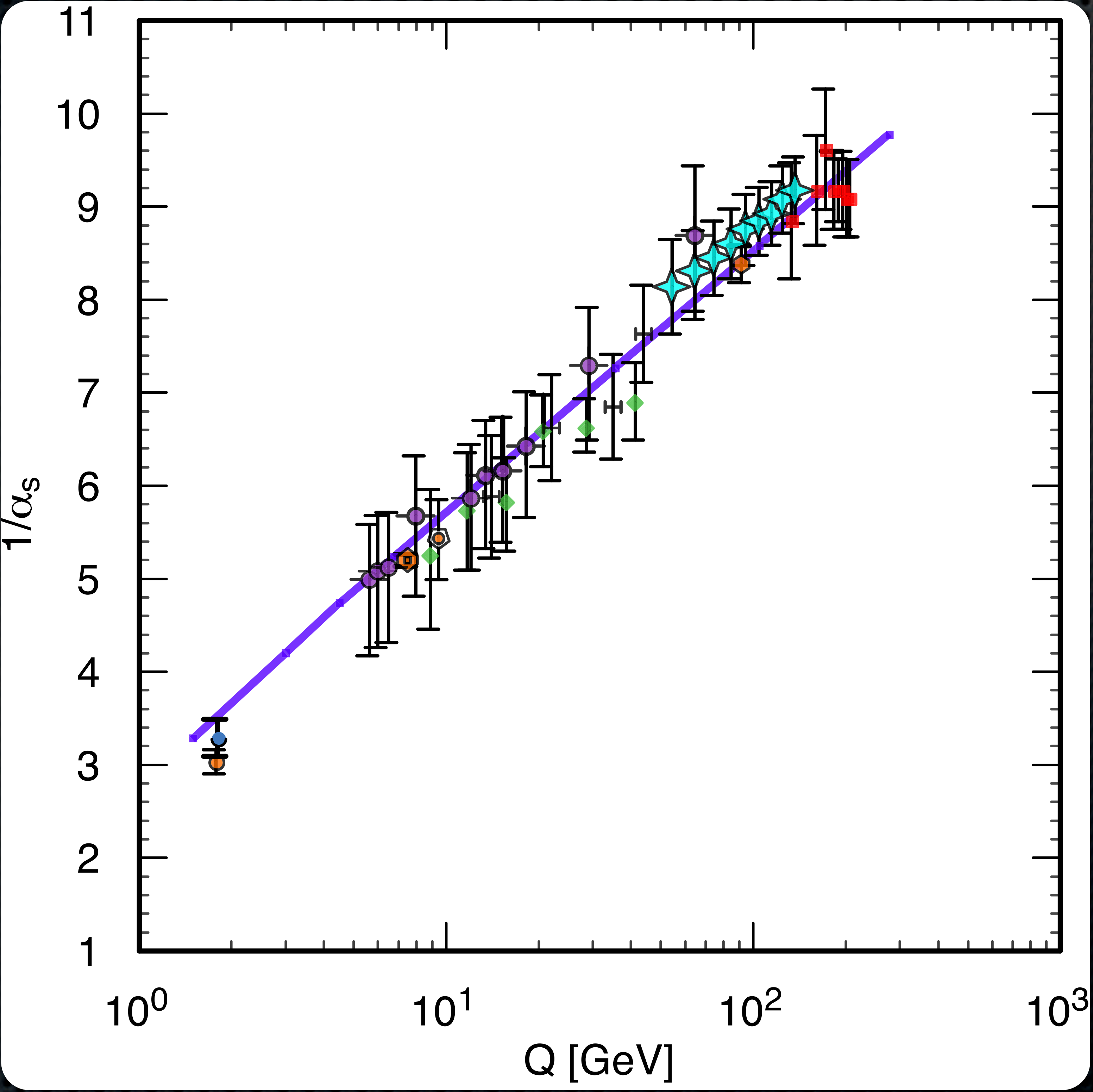
What of Yang–Mills (isospin) theory?

After SSB, still not the theory of nuclear forces

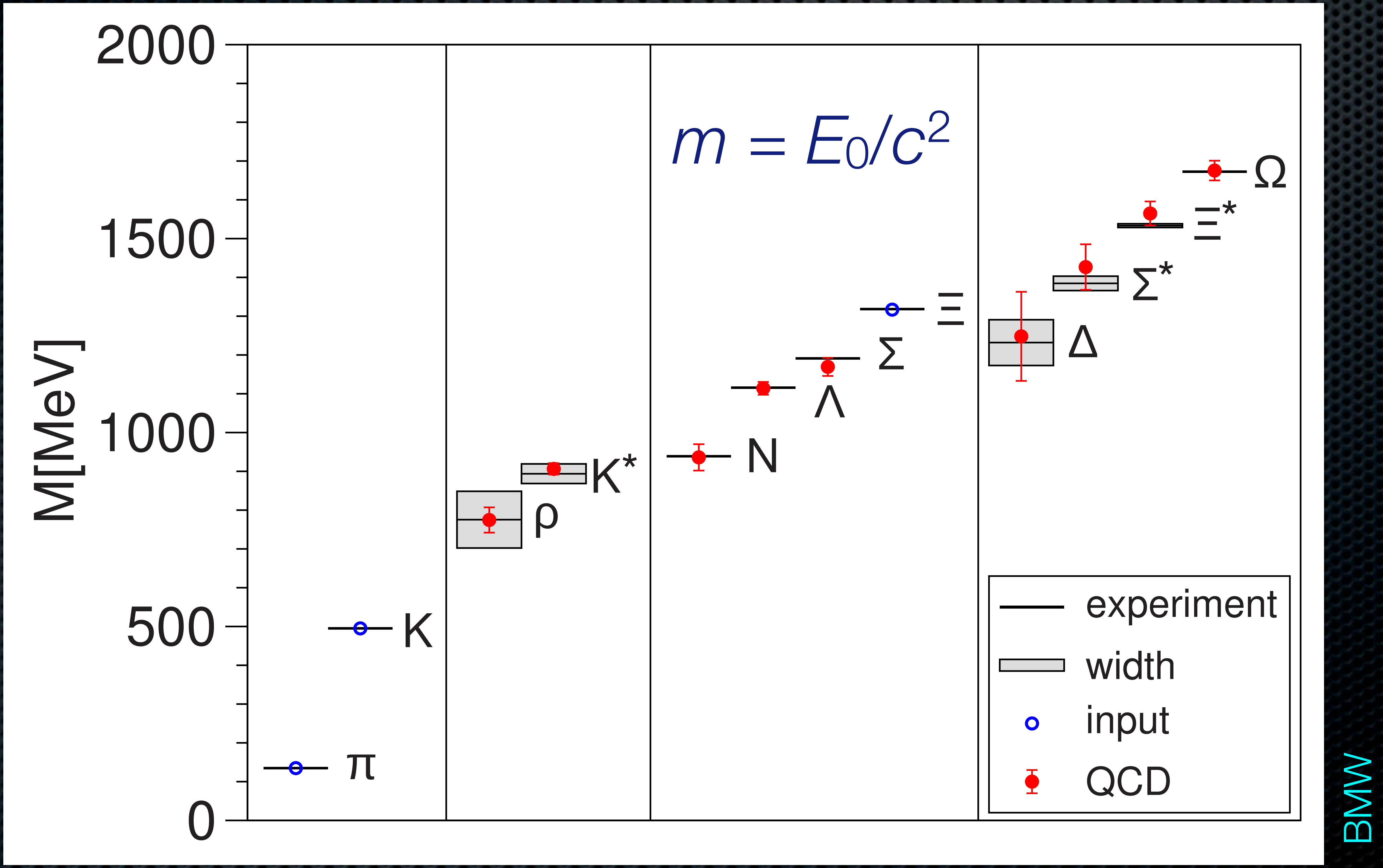
Right idea, wrong symmetry, wrong constituents

Precursor of Quantum Chromodynamics
based on SU(3) color gauge symmetry
for interactions among quarks

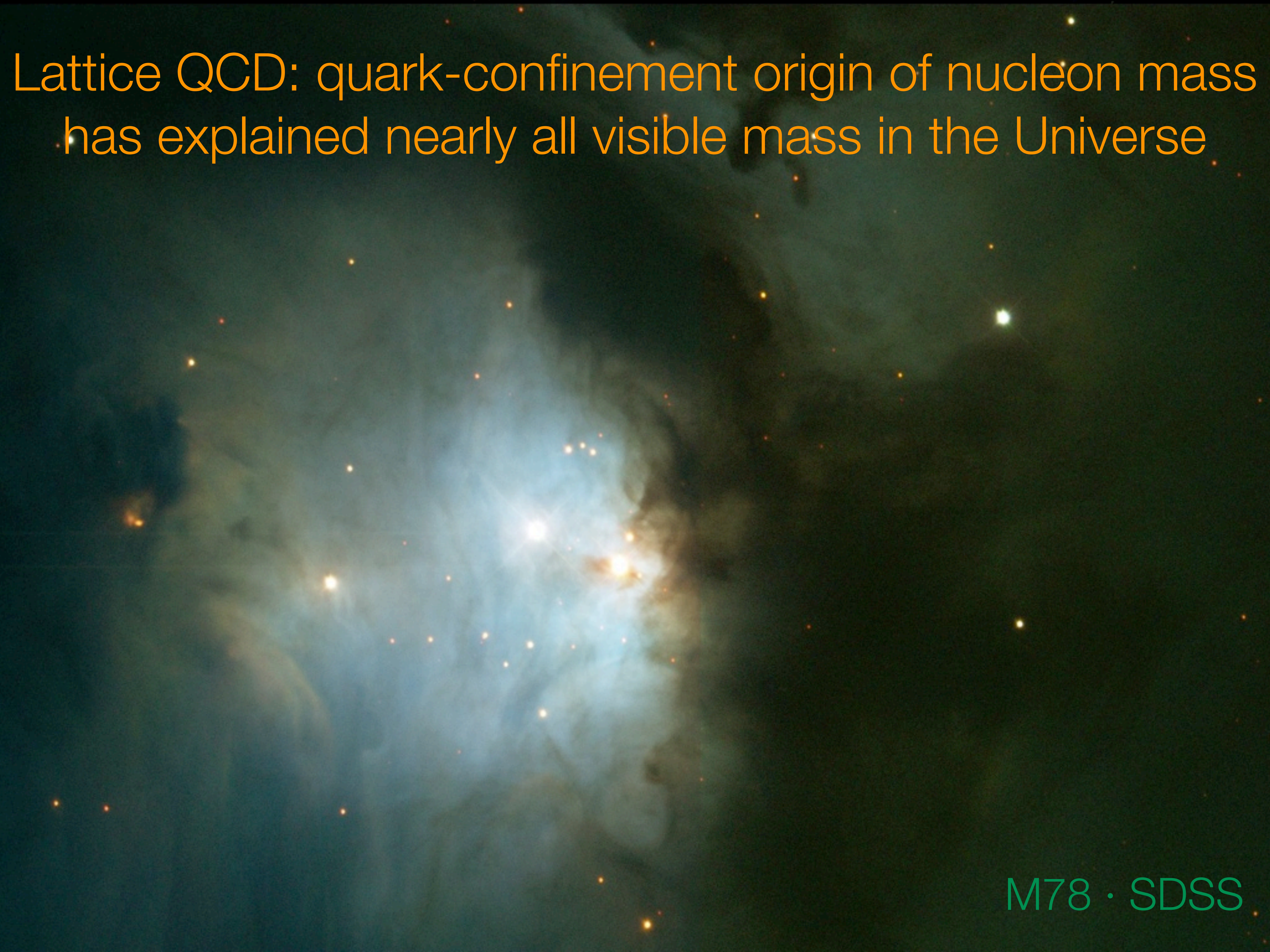
Asymptotic freedom in QCD



Light hadrons (dynamical fermions)



Lattice QCD: quark-confinement origin of nucleon mass has explained nearly all visible mass in the Universe



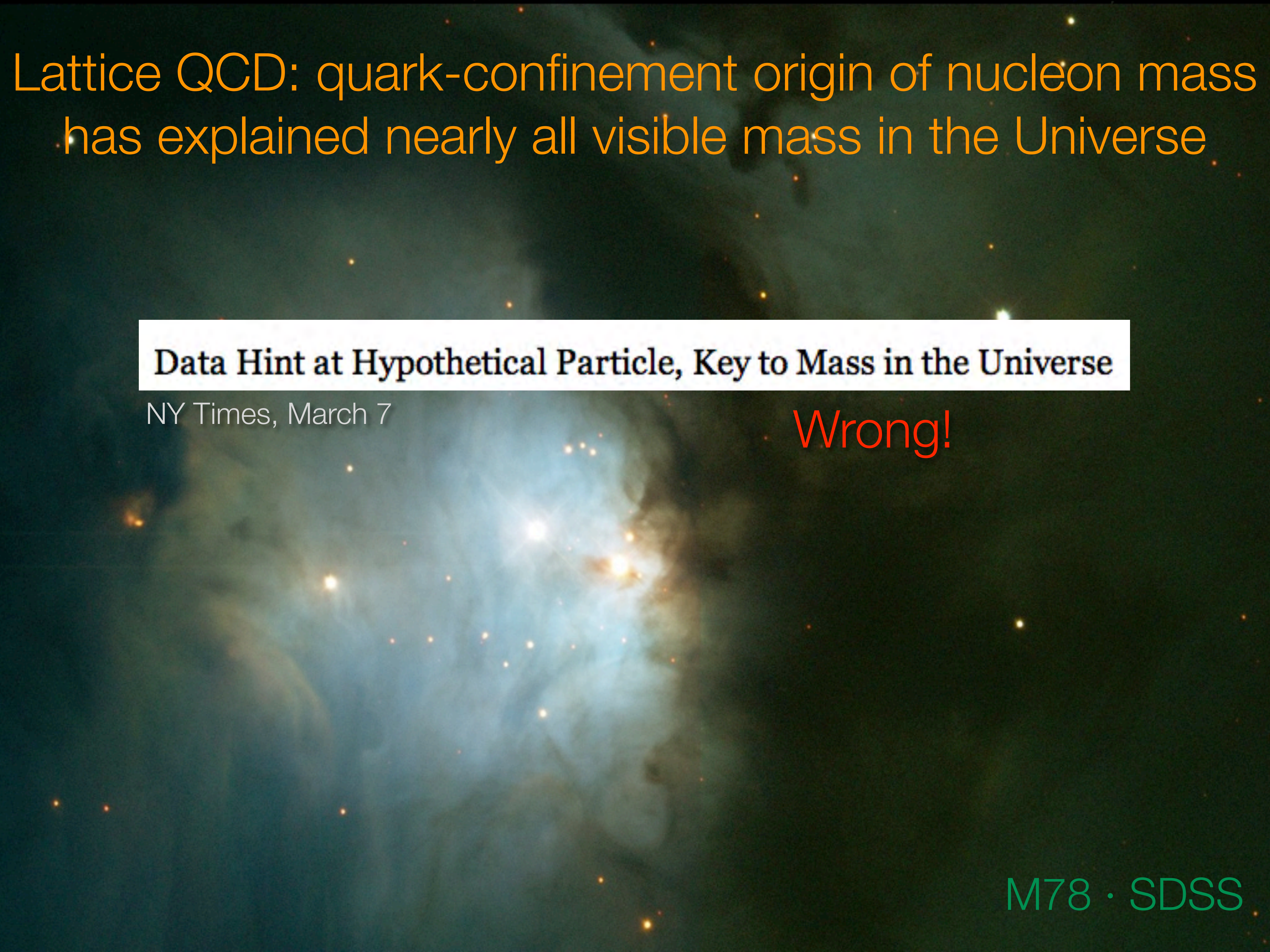
M78 · SDSS

Lattice QCD: quark-confinement origin of nucleon mass has explained nearly all visible mass in the Universe

Data Hint at Hypothetical Particle, Key to Mass in the Universe

NY Times, March 7

Wrong!



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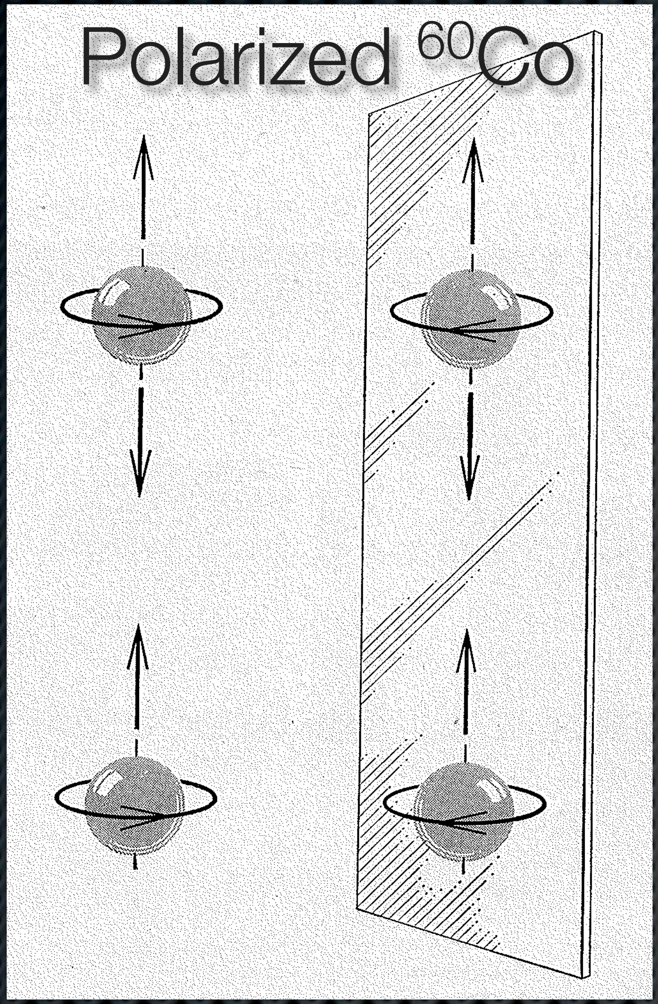
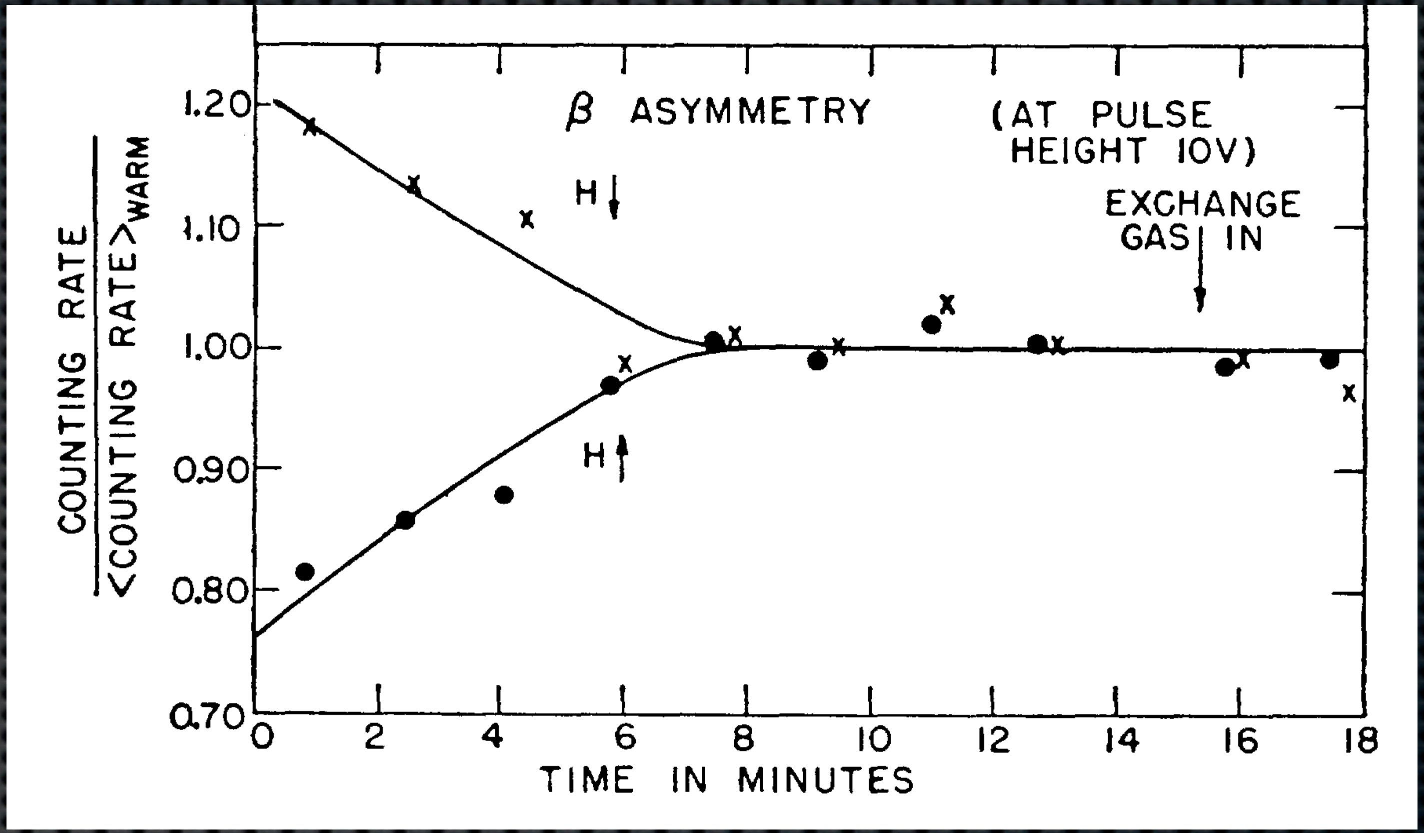
β-decay: parity not conserved!





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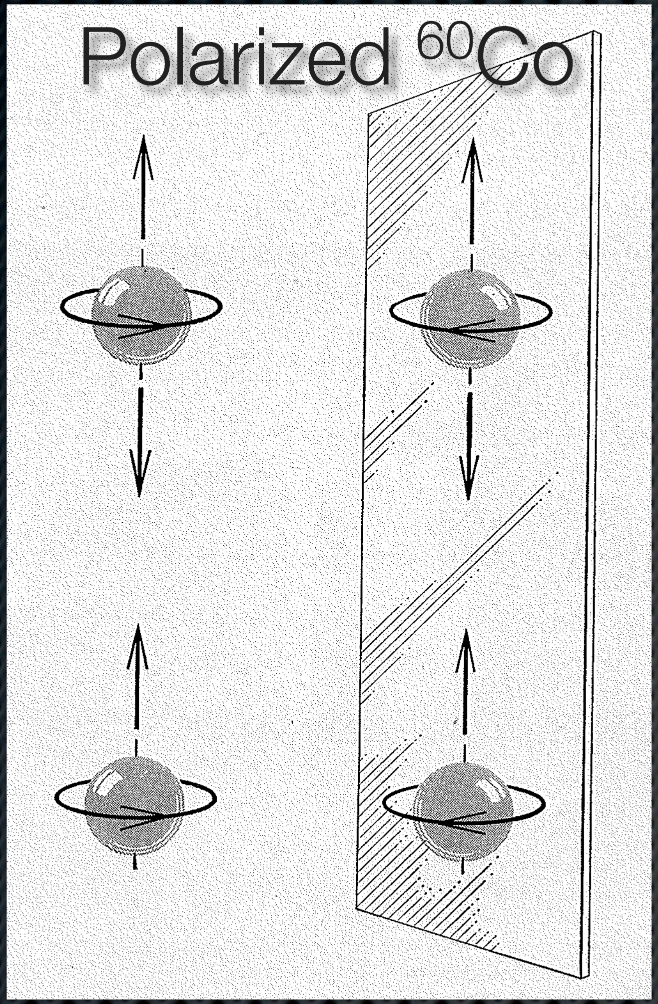
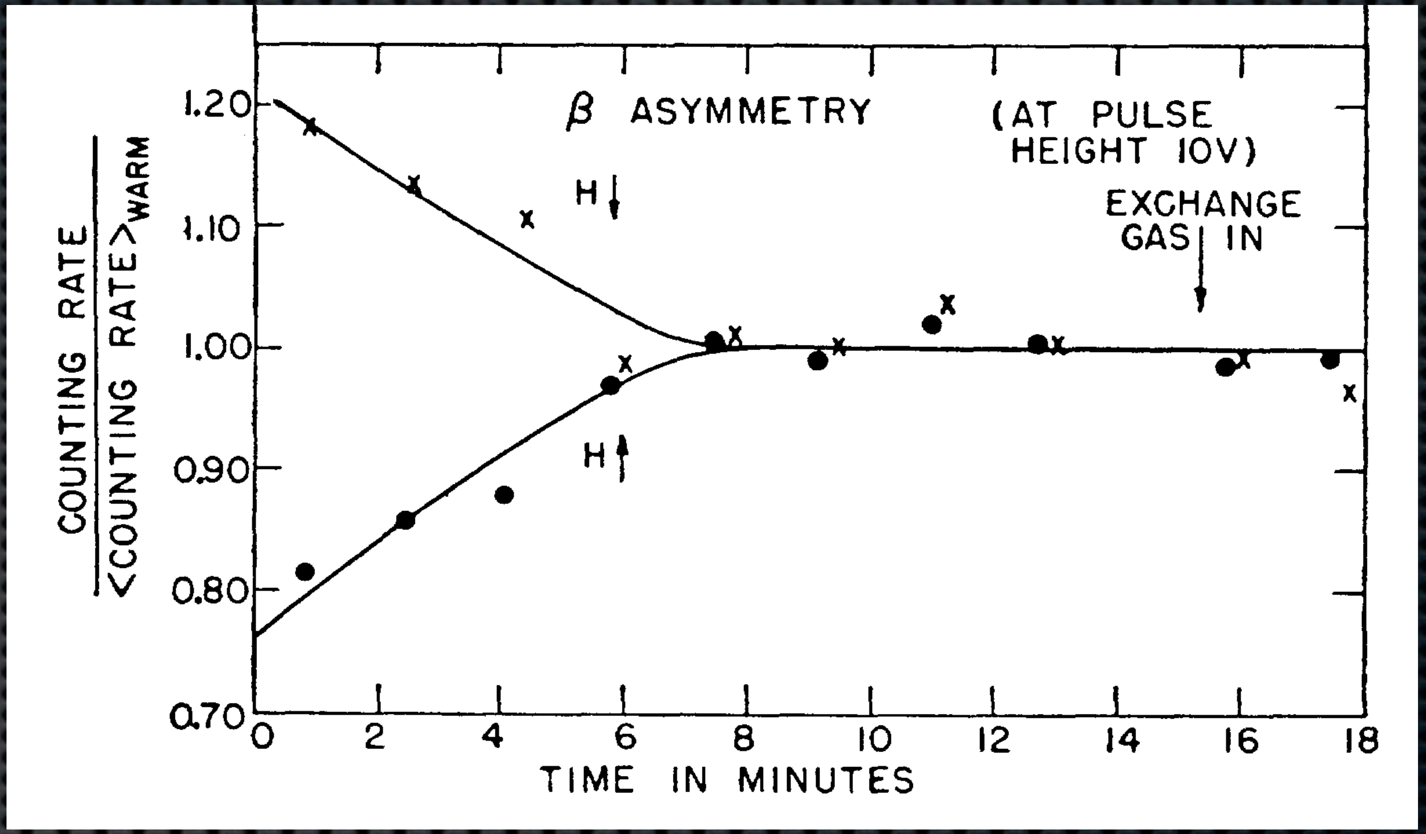
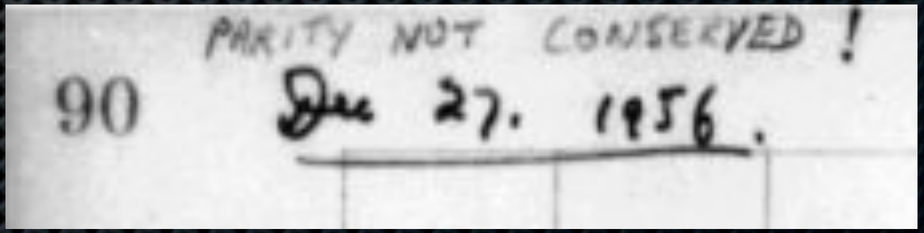




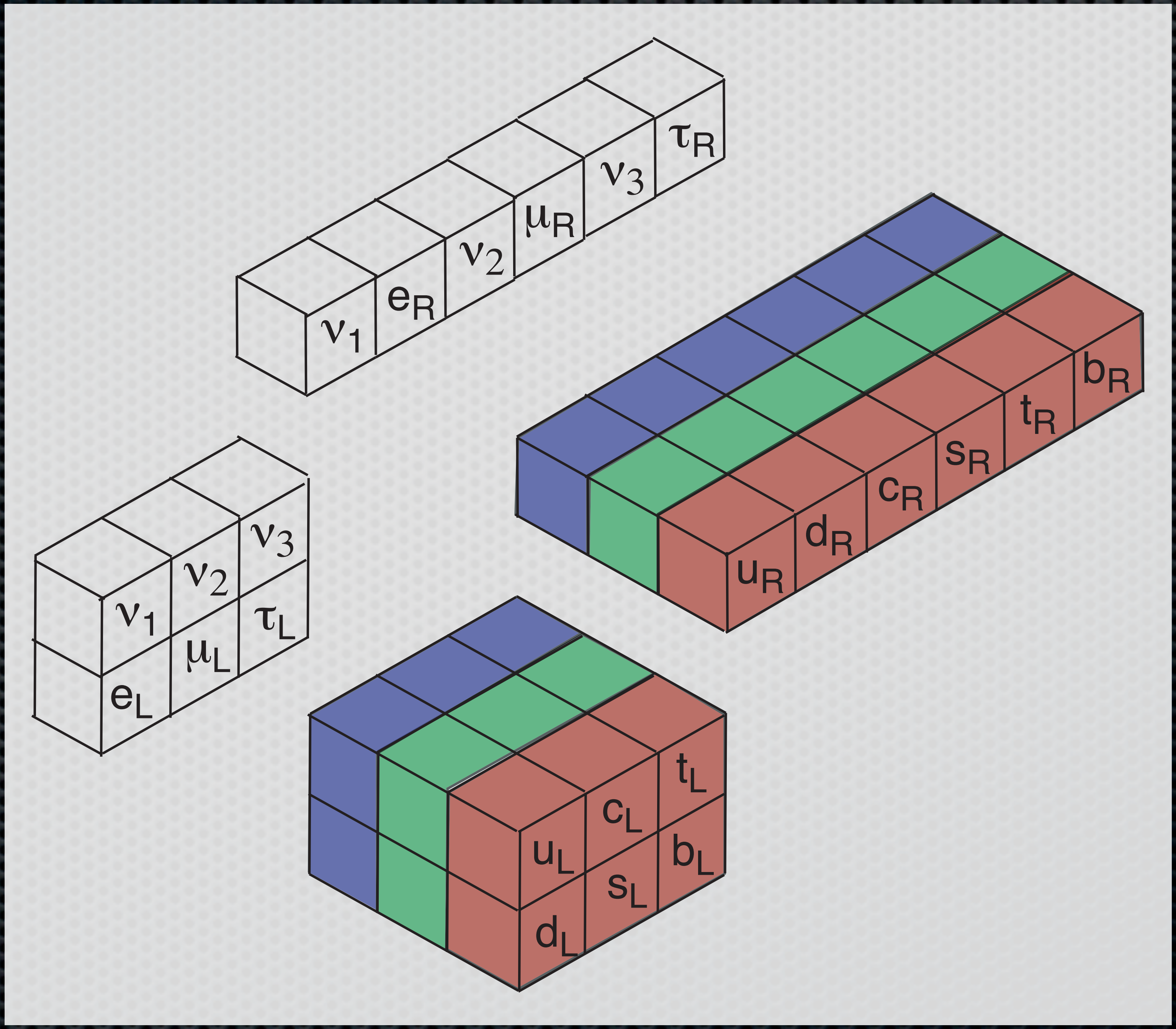
*Un*observable observed



Parity violated in weak interactions

Chien-Shiung Wu (1956) Eric Ambler

Chiral quarks and leptons



An electroweak theory

Weak isospin (left-handed)

+

weak hypercharge phase symmetry

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Sheldon Glashow

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Weak isospin (left-handed)

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3 massless gauge bosons
coupled to weak isospin

1 massless hyperphoton
coupled to weak hypercharge

massless quarks & leptons

An electroweak theory

Weak isospin (left-handed)

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Sheldon Glashow

3 massless gauge bosons coupled to weak isospin ☹

1 massless hyperphoton coupled to weak hypercharge ☹

massless quarks & leptons ☹

An electroweak theory (1967)

Contrive a vacuum to hide EW symmetry

(need 4 new fields)

Steven Weinberg

Abdus Salam

An electroweak theory (1967)

Contrive a vacuum to hide EW symmetry

(need 4 new fields)

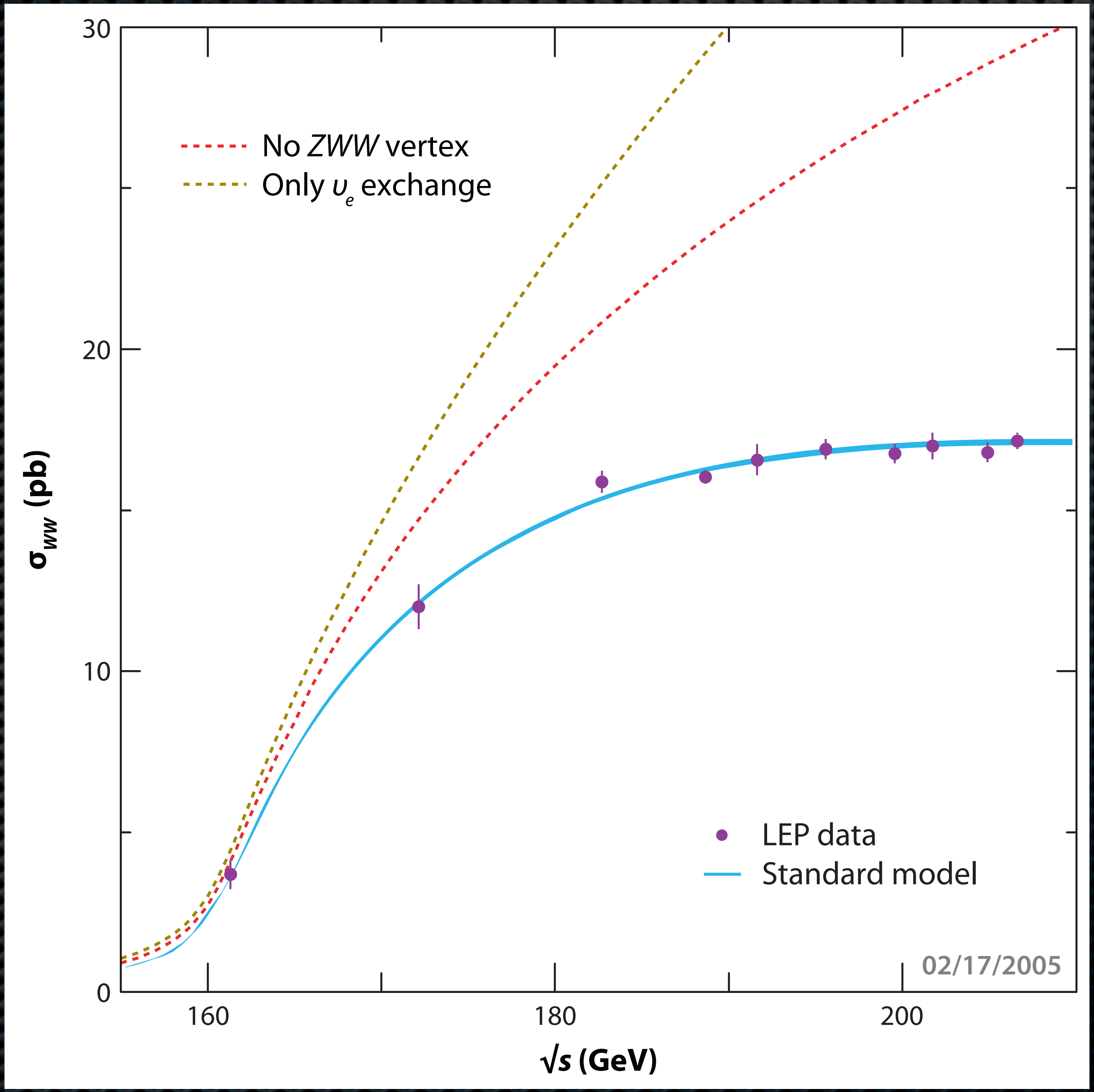
Massive W^+, W^-, Z^0
Massless photon

Massive Higgs boson

Steven Weinberg

Abdus Salam

Electroweak symmetry is real



Higgs bosons: incomplete multiplets

(w_1, w_2, z, h) form O(4) multiplet

w_1, w_2, z become longitudinal W^+, W^-, Z^0

h becomes H, remembers its roots

High-energy behavior, unitarity bound, …

See end of §III, *Phys. Rev. D16,* 1519 (1977)

Fermion mass after SSB

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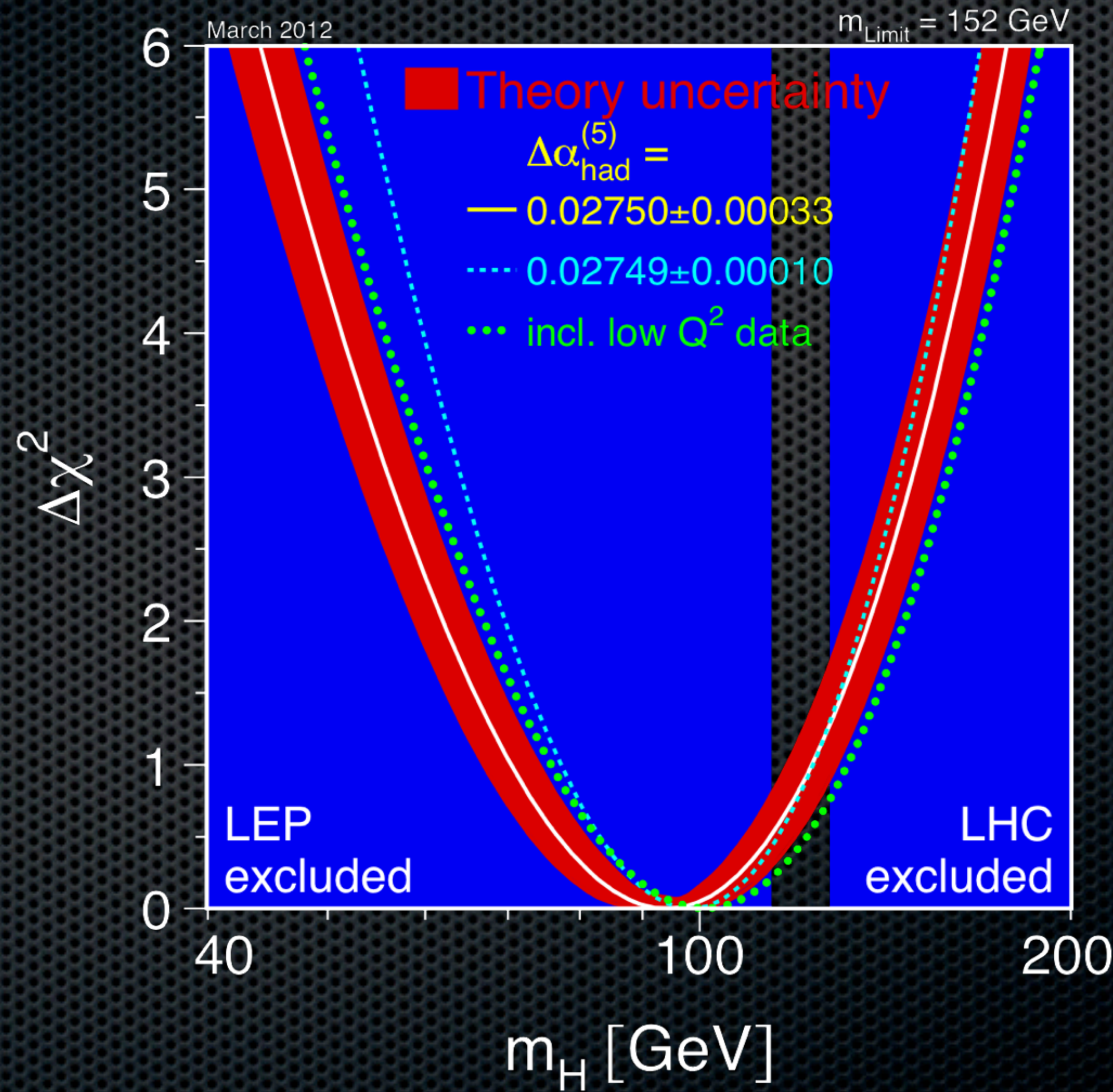
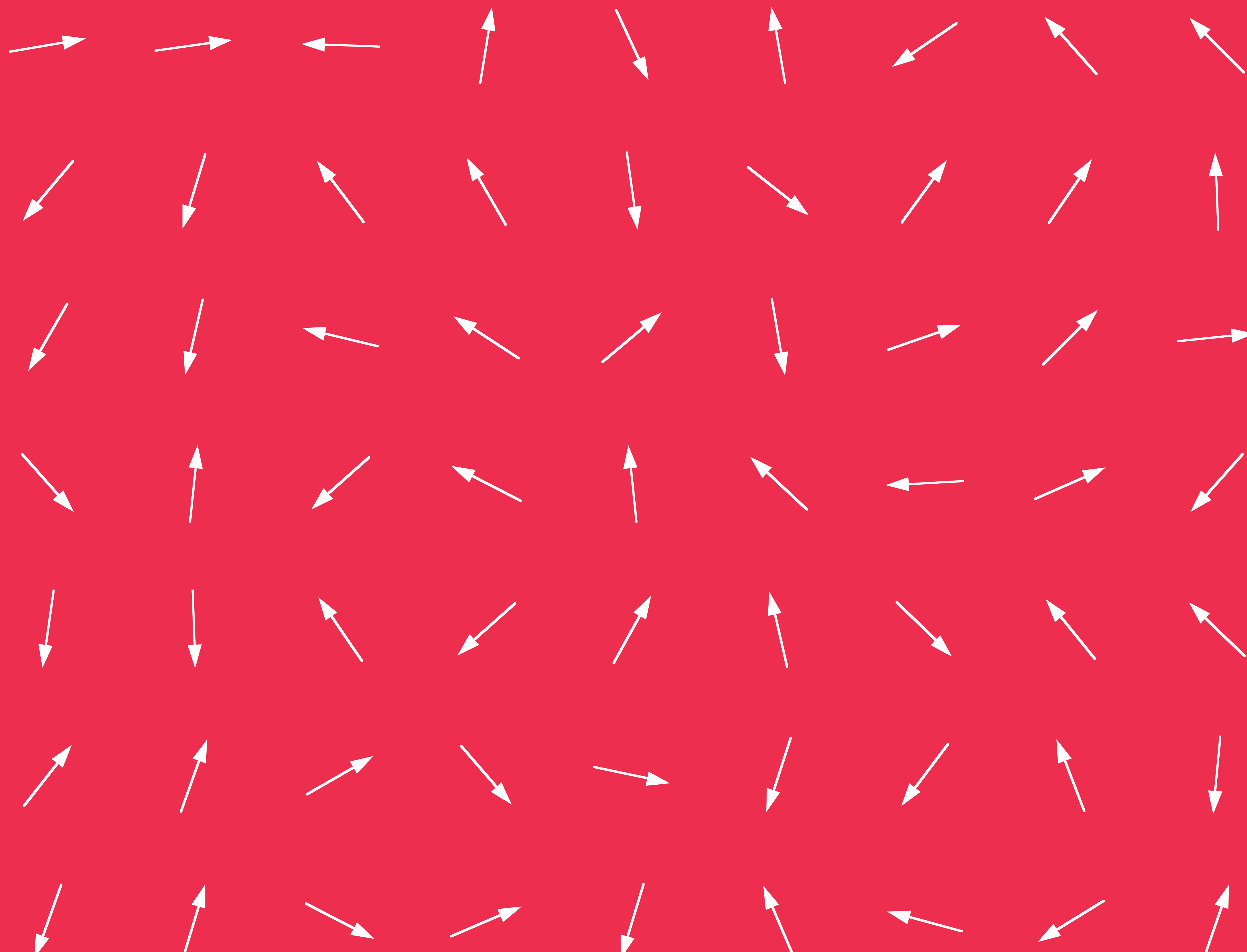
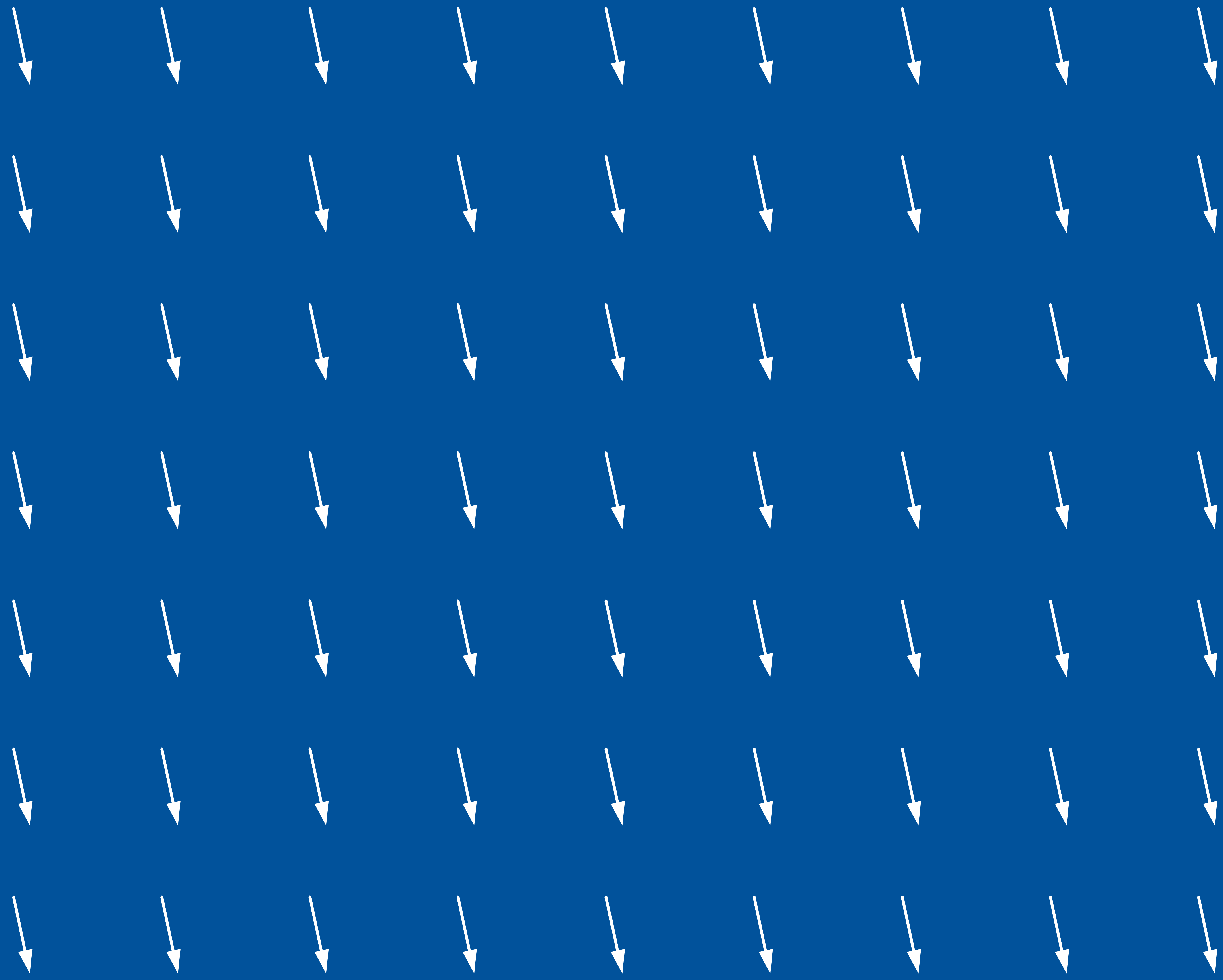
Fermion masses: physics beyond standard model

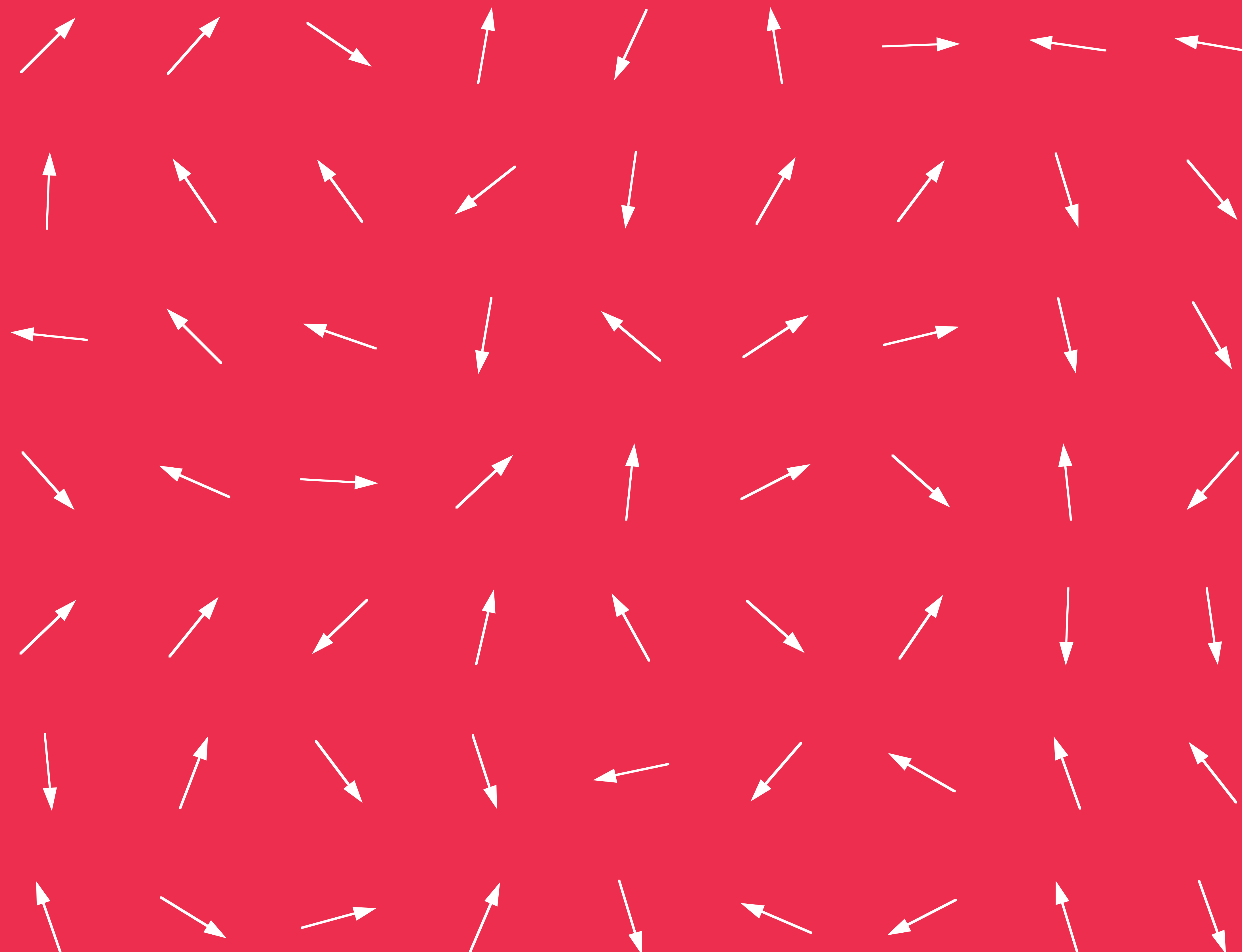
H couplings to W, Z tested




SUUNTO
M3
1:15000
1:50000
1:25000







World without SSB

Electron and quarks have no mass

QCD confines quarks into protons, etc.

Nucleon mass little changed

Surprise: QCD hides EW symmetry,

gives tiny masses to W, Z

Massless electron: atoms lose integrity

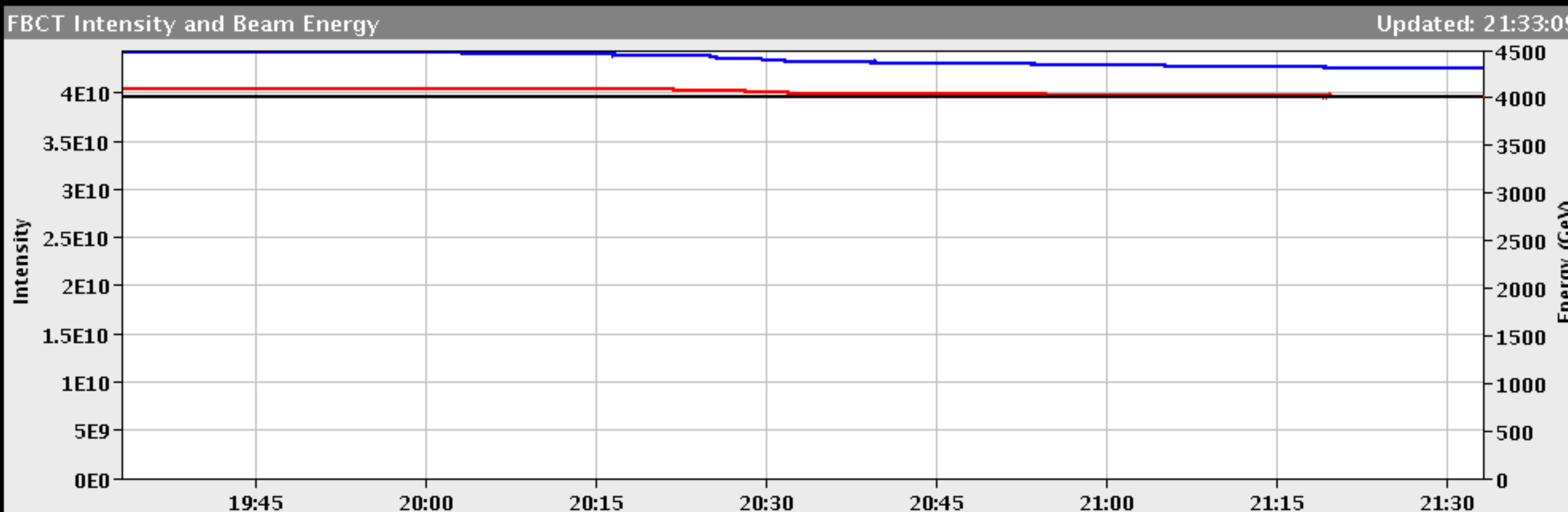
No atoms means no chemistry, no stable composite structures like liquids, solids, …

arXiv:0901.3958

LHC Page1 | Fill: 2468 | E: 4000 GeV | t(SB): 00:00:00 | 04-04-12 21:33:08

BEAM SETUP: ADJUST

Energy:	4000 GeV	I(B1):	3.92e+10	I(B2):	4.16e+10



Comments 04-04-2012 20:51:56 :

Next: aperture check at collision

Stable beams not before 23:00.

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	true	true
Setup Beam	true	true
Beam Presence	true	true
Moveable Devices Allowed In	false	false
Stable Beams	false	false

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